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ABSTRACT

The federal High Performance Computing and Communications (HPCC) program was created to accelerate the development of future generations of high performance computers and networks and the use of these resources in the federal government and throughout the American economy. This report describes the HPCC program which is developing computing, communications, and software technologies for the 21st Century. The HPCC program will provide key parts of the technological foundation for the National Information Infrastructure. The program is organized into the following five components: High Performance Computing Systems (HPCS); National Research and Education Network (NREN); Advanced Software Technology and Algorithms (ASTA); Information Infrastructure Technology and Applications (IITA); and Basic Research and Human Resources (BRHR). The report is divided into four sections: executive summary; program accomplishments and plans; high performance living today and tomorrow; and the HPCC program in summary. A glossary of terms and a list of contacts are included. (JLB)

High Performance Computing and Communications:

Cover images:

1. Predicted (yellow) and observed (orange) track of Hurricane Emily

2. Simulation of the behavior of materials at the fundamental atomic scale

3. High precision manufacturing of a copper mirror for a laser welder

4. Blood streaming through the aortic valve in a computer model of the heart

5. Father and daughter at a High Performance Computing Research Center

HIGH PERFORMANCE COMPUTING AND COMMUNICATIONS

TECHNOLOGY FOR THE NATIONAL INFORMATION INFRASTRUCTURE

A Report by the Committee on Information and Communication

National Science and Technology Council

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20500

MEMBERS OF CONGRESS:

I am pleased to forward with this letter "High Performance Computing and Communications: Technology for the National Information Infrastructure" prepared by the Committee on Information and Communication (CIC) of the National Science and Technology Council (NSTC). This report, which supplements the President's Fiscal Year 1995 Budget, describes the High Performance Computing and Communications (HPCC) Program, which prior to the creation of the NSTC, was coordinated by the Committee on Physical, Mathematical, and Engineering Sciences (CPMES) within the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET).

The interagency HPCC Program is developing computing, communications, and software technologies for the 21st century. It is fully supportive of and coordinated with the Administration's National Information Infrastructure (NII) Initiative, which was described in the NII Agenda for Action released on September 15, 1993. The Program will provide key parts of the technological foundation for the NII and develop and demonstrate selected "National Challenge" applications. National Challenges are major societal needs that computing and communications technology can help address in key areas such as health care, manufacturing, digital libraries, education and lifelong learning, electronic commerce, energy management, the environment, national security, and government services.

NII technologies are critically interwoven with and dependent upon high performance computing and communications capabilities and the software needed to address scientific and engineering "Grand Challenges" such as forecasting the weather, building safer and more energy efficient aircraft, designing life saving drugs, and understanding how galaxies are formed. The Program has accelerated the development of these technologies by supporting the researchers who create and apply them and the educators who teach others how to use them.

In formulating its research and development agenda, the HPCCIT Subcommittee and its participating agencies have worked closely with industry and academia. These key stakeholders have been providing informal input to the Program, and we are currently formalizing the process for ongoing private sector participation in conjunction with the new framework of the NSTC. Donald A. B. Lindberg, Chair of the HPCCIT Subcommittee, other members of the Subcommittee, their associates, and staff are to be commended for their efforts on this report and on the Program itself.

John H. Gibbons
Assistant to the President
for Science and Technology

Table of Contents

I. Executive Summary 1

II. Program Accomplishments and Plans

1. Networking 7
1.1. The Internet 7
1.2. The Interagency Internet 7
1.3. Gigabit Speed Networking R&D 9
1.4. Network Security 10
2. High Performance Computing Systems 10
3. High Performance Computing Research Centers (HPCRCs) 12
4. Software 14
4.1. Systems Software and Software Tools 15
4.2. Scientific Computation Techniques 16
4.3. Grand Challenge Applications 16
Aircraft 17
Computer Science 17
Energy 18
Environmental Monitoring and Prediction 18
Molecular Biology and Biomedical Imaging 20
Product Design and Process Optimization 21
Space Science 22
5. Technologies for the National Information Infrastructure (NII) 22
5.1. Information Infrastructure Services 22
5.2. Systems Development and Support Environments 23
5.3. Intelligent Interfaces 24
6. National Challenges 25
Digital Libraries 25
Crisis and Emergency Management 25
Education and Lifelong Learning 26
Electronic Commerce (EC) 26
Energy Management 26
Environmental Monitoring and Waste Minimization 26
Health Care 28
Manufacturing Processes and Products 29
Public Access to Government Information 29
7. Basic Research 30
8. Training and Education 31
9. HPCC Program Management 32
10. Information about the HPCC Program 33

III. High Performance Living Today and Tomorrow 35

Crisis Management: Earthquake Relief in the Year 2000 36
Education and Lifelong Learning 37
Education and the NII Circa 2000 37
Lifelong Learning 37
Electronic Commerce 38
Electronic Banking 38
Electronic Brokering 38
Buying a Car in the Year 2000 39
Increased Productivity through Improved Environmental Data 40
Environmental Monitoring in the Year 2000 41
Delivering Health Care to Remote Areas 42

IV. The HPCC Program in Summary

HPCC Program Goals 45
HPCC Agencies 45
HPCC Program Strategies 46
Overview of the Five HPCC Program Components 47
Evaluation Criteria for Agency Participation in the HPCC Program 48
Agency Responsibilities 49
Agency Budgets by HPCC Program Components 50
HPCCIT Reporting Structure and Subcommittee Roster 51

V. Glossary 53

VI. Contacts 57

Executive Summary

The Federal High Performance Computing and Communications (HPCC) Program was created to accelerate the development of future generations of high performance computers and networks and the use of these resources in the Federal government and throughout the American economy.

In the early 1980s American scientists, engineers, and leaders in government and industry recognized that advanced computer and communications technologies could provide vast benefits throughout not just the research community but the entire U.S. economy. Senior government, industry, and academic scientists and managers initiated and are implementing the HPCC Program to extend U.S. leadership in these technologies and to apply them to areas of profound impact on and interest to the American people. The National High-Performance Computing Program was formally established following the passage of the High Performance Computing Act of 1991 (Public Law 102-194), introduced by then Senator Gore.

The scalable high performance computing systems, advanced high speed computer communications networks, and advanced software being developed in the HPCC Program are necessary for science and engineering and will contribute critical components of the National Information Infrastructure (NII). This infrastructure is essential to our national competitiveness. It will enable us to build digital libraries, enhance education and lifelong learning, manage our energy resources better, monitor and protect the environment, and improve health care, manufacturing, national security, and public access to government information.

The Program is planned, funded, and executed through the close cooperation of Federal agencies and laboratories, private industry, and academia. These efforts are directed toward ensuring that to the greatest extent possible the Program meets the needs of all communities involved and that its results are brought into the research and educational communities and into the commercial marketplace as effectively as possible.

The Program is well on its way toward meeting its original goals:

- More than a dozen high performance computing research centers are in operation nationwide. More than 100 scalable high performance systems are in operation at these centers. These include large scale parallel systems, vector parallel computing systems, hybrid systems, workstations and workstation clusters, and networked heterogeneous systems. The largest of these systems now provides more than 50 gigaflops (billions of floating point operations per second) performance on large problems. The HPCC Program's 1996 goal of developing high performance systems capable of sustained teraflops (trillions of floating point operations per second) performance is well on the way to being met.

- The HPCC-funded communications networks, part of the Internet, continue to experience phenomenal growth in size, speed, and number of users. These networks enable researchers to access high performance computers and advanced scientific instruments easily, and have begun to allow independence of geographical location.

- One illustration of the global reach of HPCC technology is that the Internet now extends across the country and throughout much of the world. The Internet links more than two million computers, more than 15,000 networks in the U.S. and more than 6,000 outside the U.S., and 1,000 4-year colleges and universities, 100 community colleges, 1,000 high schools, and 300 academic libraries in the U.S.

- More than half a dozen gigabit testbeds conduct research in high capacity networks.

These network testbeds connect 24 sites, including many of the high performance computing research centers. Seven Federal agencies, 18 telecommunications carriers, 12 universities, and two state supercomputer centers participate. The testbeds develop technologies to handle the NII's increased demand for computer communications, along with greater accessibility, interoperability, and security. The Program goal of demonstrating gigabit (billions of bits) per second transmission speeds by 1996 is well on the way to being met.

- Teams of researchers are using scalable systems to discover new knowledge and demonstrate new capabilities that were not possible with earlier technologies. These researchers are addressing the "Grand Challenges," fundamental problems in science and engineering with broad economic and scientific impact whose solutions can be advanced by applying high performance computing techniques and resources. Many of these challenges are associated with HPCC agency missions. Agencies are increasingly working with U.S. industry to use their Grand Challenge applications software and develop new software that will improve commercial and industrial competitiveness.

Users of the new scalable computing systems with their high performance on large problems and larger memories are able to address more complex, more realistic problems. We are beginning to understand our world better and to improve our lives:

- Improved modeling of the Earth and its atmosphere has sharpened our ability to predict the movement and characteristics of storms and other forms of severe weather. With improved forecasts, there will be more lives saved and an overall positive economic impact due to reduced property loss and evacuation of smaller endangered areas along the coast and elsewhere.

- New air and water quality models are enabling improved environmental decision making.

- Improvements in the design and manufacture of goods are yielding better products. Both the production processes and products such as cars and airplanes are becoming more energy efficient.

- We are learning more about how the human body functions and are improving our ability to diagnose and treat diseases.

- The thousands of researchers who develop fundamental HPCC and NII technologies and applications form the vanguard that hardware and software vendors rely upon to promote the use of high performance computers and communications throughout the U.S. economy. Hundreds of teachers and thousands of students access HPCC resources, and the Program conducts hundreds of training events for thousands of trainees. Dozens of small systems have been installed at colleges and universities. The goal of these efforts is to train a nation of knowledgeable users and thereby fully incorporate HPCC and NII technologies and applications into the U.S. economy.

In his State of the Union speech on January 24, 1994, President Clinton called for connecting every classroom, library, clinic, and hospital in America into a "national information superhighway" by the year 2000. He said, "Instant access to information will increase productivity. It will help educate our children. It will provide better medical care. It will create jobs." The HPCC Program is helping to fulfill this vision by developing much of the underlying technology for the NII, enabling the development of "National Challenge" applications, and demonstrating a variety of pilot applications. National Challenges are fundamental applications that have broad and direct impact on the Nation's competitiveness and the well-being of its citizens, and that can benefit from the application of HPCC technologies and resources. They include crisis and emergency management, digital libraries, education and lifelong learning, electronic commerce, energy demand and supply management, environmental monitoring and waste minimization, health care, design of man-

ufacturing processes and products, and public access to government information. Some of the early National Challenge applications, such as electronic commerce, will mature to become services in the NII, enabling a wider range of future National Challenge applications.

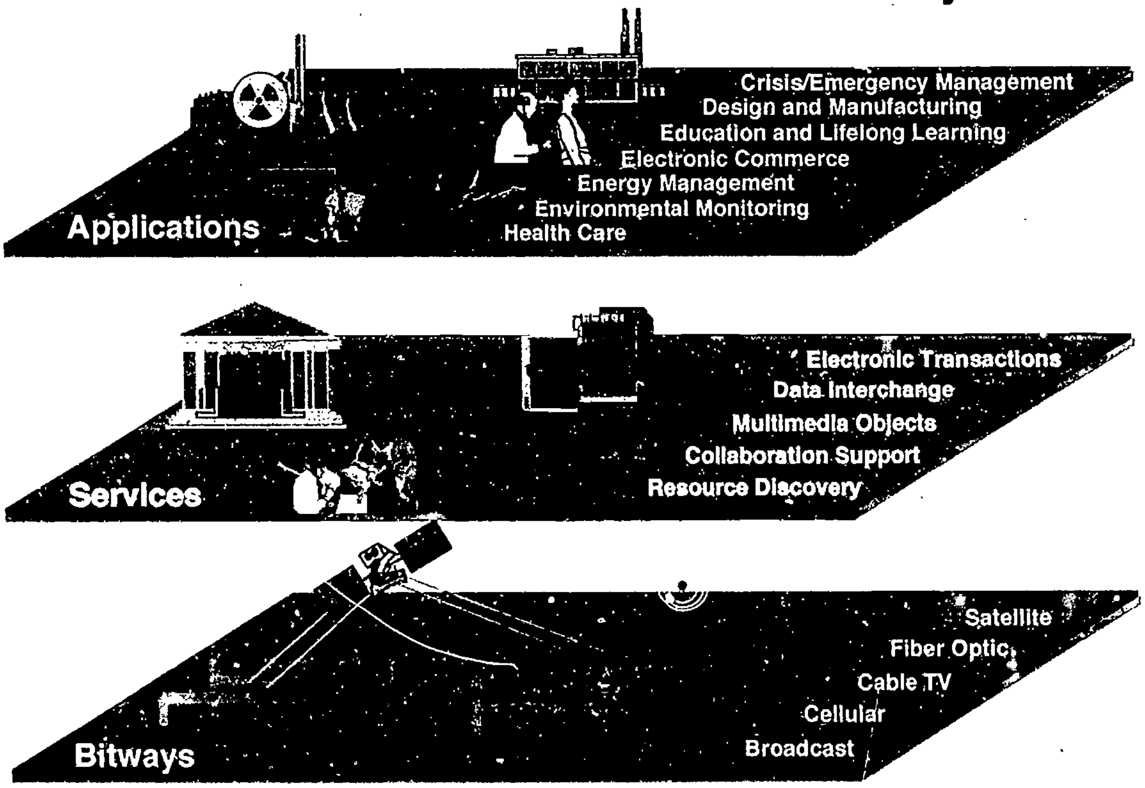
Pending Congressional legislation introduced in 1993 would formally expand the Program to include such responsibilities.

HPCC and the NII are tightly interwoven. While the Federal agencies that participate in the HPCC Program are working to enable the NII, it is the private sector that will deploy it. Many policy and regulatory obstacles will be cleared through the workings of the interagency Information Infrastructure Task Force.

The capabilities being developed under the HPCC Program provide much of the technology base critically needed for the National Information Infrastructure:

- Scalable computing technologies provide the foundation for the computing systems needed by the NII. For example:
  - The microprocessors at the heart of today's most powerful scalable parallel computers appear in relatively inexpensive desktop workstations and personal computers today and will be found in the information appliances in the homes of tomorrow.
  - The same technology that provides high speed connectivity between computer pro-

National Information Infrastructure Layers



In FY 1994 the HPCC Program began expanding its technical scope to include enabling technologies to accelerate the development of a National Information Infrastructure. The fundamentally advantageous technical properties of scalable high performance computing and communications make HPCC technologies critical for the National Information Infrastructure.

cessors and memory can be used to build switches for the NII's high speed networks.

- The same "client/server" technology used to supply data from remote computers to Grand Challenge computations can be used to disseminate information to American households.

- NII applications such as the entertainment industry's "video on demand" will soon use the scalable parallel computing and mass storage systems that have long been part of high performance computing research centers.

- The technology for the high bandwidth networks needed by Grand Challenge researchers to move data between computers and to distribute information to users of the NII is being developed at the gigabit testbeds.

- The software technologies, including operating systems and software development environments, being developed under HPCC have widespread application to general-purpose systems, not just those identified as "numerically intensive."

- Many National Challenge applications depend upon computationally intensive Grand Challenge applications. For example:

  - Improving health care requires biomedical research (such as improved molecular design of drugs).

  - Improved environmental monitoring requires computationally intensive environmental models.

  - Effective response to natural and man-made disasters depends on weather forecasting and environmental models.

  Developing advanced methods for product and process design and manufacturing requires numerically-intensive prototyping of those products and processes.

  - The "information" in the National Information Infrastructure will include the data used by and the results from Grand Challenge research.

The NII places additional demands on HPCC research and development. Scalability issues must be addressed — the technologies used to serve thousands of researchers and educators must be scaled up to serve millions of NII users. With the larger number of NII users and their greater diversity of interests and skills, more ubiquitous alternative "on-ramps" to the emerging high bandwidth networks of the NII must be examined. For example, at the Monte Vista High School in Cupertino, CA, Vice President Gore visited a class of students who were directly accessing the Internet over the local cable TV system. This technology was developed under HPCC sponsorship.

New services are being developed to support multimedia applications, digital libraries technologies, appropriate privacy and security protection, and increasingly higher levels of performance. Software development environments and building blocks for interfacing humans and computers must be created. These new tools will enable application developers to construct complex, large-scale, network-based, user-friendly, and information-intensive applications. These technologies provide the foundation upon which National Challenge applications will be developed.

The HPCC Program reports to the Director of the Office of Science and Technology Policy. At his direction, budget oversight is provided by the National Science and Technology Council through its Committee on Information and Communication. The Program is managed by the High Performance Computing, Communications, and Information Technology Subcommittee. The National Coordination Office (NCO) for High Performance Computing and Communications completed its first year of operation in September 1993. During that year, it held more than 50 meetings with representa-

tives from the U.S. Congress, state and local governments, foreign governments, industry, and universities.

HPCC Program agencies work closely with other government agencies, industry, and academia in developing, supporting, and using HPCC and other NII-associated technologies. The NCO and HPCC Program agencies work with members of the Information Infrastructure Task Force in addressing NII policy issues, and with other Federal agencies involved in helping schools, libraries, and medical facilities become part of the NII. Industrial, academic, and professional societies also provide critical analyses of the HPCC Program through conferences, workshops, and reports. Through these efforts, Program goals and accomplishments are better understood and Program planning and management are strengthened.

The 10 agencies that participate in the HPCC Program are:

ARPA	Advanced Research Projects Agency
NSF	National Science Foundation
DOE	Department of Energy
NASA	National Aeronautics and Space Administration
NIH	National Institutes of Health
NSA	National Security Agency
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
EPA	Environmental Protection Agency
ED	Department of Education

Through coordinated planning and research and development, these agencies are developing an integrated infrastructure of HPCC and NII technologies. No individual agency has either the mission or the expertise to develop all components of the infrastructure, but each plays a necessary and unique role in the overall program.

The HPCC Program is organized into five components with the following key aspects:

High Performance Computing Systems (HPCS)

- Accelerated development of scalable computing systems, with associated software, including networks of heterogeneous systems ranging from affordable workstations to large scale high performance systems

- Technologies to enable the use of advanced component, packaging, mass storage, and communications technologies for the design of large scale parallel computing systems

National Research and Education Network (NREN)

- Broadened network connectivity of the research and education communities to high performance computing and research resources

- Accelerated development and deployment of networking technologies

Advanced Software Technology and Algorithms (ASTA)

- Prototype solutions to Grand Challenge problems

- Improved algorithms, software technologies, and software tools for more efficient use of scalable computing systems

- Deployment of advanced high performance computing systems

Information Infrastructure Technology and Applications (IITA)

- Prototype solutions to National Challenge problems using HPCC enabling technologies

- Accelerated development and deployment of NII enabling technologies

Basic Research and Human Resources (BRHR)

- Support for research, training, and education in computer science, computer engineering, and computational science, and infrastructure enhancement through the addition of HPCC resources

The total FY 1994 HPCC Program budget for 10 participating agencies is $938 million. For FY 1995, the proposed HPCC Program budget for nine agencies is $1.155 billion, representing a 23 percent increase over the appropriated FY 1994 level.

HPCC Program Accomplishments and Plans

1. Networking

The HPCC Program provides network connectivity among advanced computing resources, scientific instruments, and members of the research and education communities. The Program has successfully accommodated the phenomenal growth in the number of network users and their demands for significantly higher and ever increasing speeds while maintaining operational stability. R&D in advanced networking technologies is guiding the development of a commercial communications infrastructure for the Nation. The development and deployment of this new technology is jointly funded and conducted by the HPCC Program, state and local governments, the computer and telecommunications industries, and academia.

1.1. The Internet

One illustration of the global reach of HPCC technologies is that the Internet now extends across the country and around much of the world. Initially the domain of government scientists and U.S. academics, by the beginning of FY 1994:

- Almost two million computers were accessible over the Internet.
- More than 15,000 regional, state, and local U.S. networks and 6,300 foreign networks in approximately 100 countries were part of the Internet.
- Nearly 1,000 4-year colleges and universities, 100 community colleges, 1,000 U.S. high schools, and 300 academic libraries in the U.S. were connected.

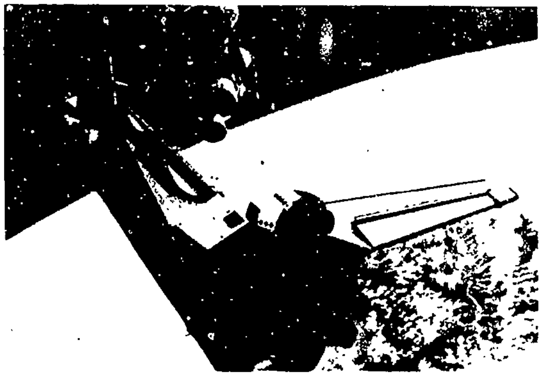
The HPCC Program's Internet investment primarily supports the high speed "backbone" networks linking Federally-funded high performance computing centers.

1.2. The Interagency Internet

The Interagency Internet, that portion of the Internet funded by HPCC, is a system of value-added services carried on the Nation's existing telecommunications infrastructure for use in federally-funded research and education. Its three-level architecture consists of high speed backbone networks (such as NSFNET) that link mid-level or regional networks, which in turn connect networks at individual institutions. At the beginning of the HPCC Program in FY 1992, most of the backbones were running at T1 speeds (1.5 Mb/s — megabits per second or millions of bits per second), and international connections had been established. Peak monthly traffic on NSFNET had reached 10 billion packets (of widely varying size). In FY 1992, NSFNET speed was upgraded to T3 (45 Mb/s) and NSF made awards to industry for network registration, information, and database services and for a Clearinghouse for Networked Information Discovery and Retrieval. By the beginning of FY 1994:

- Peak monthly NSFNET traffic reached 30 billion packets.
- DOE established six ATM (asynchronous transfer mode) testbeds to evaluate different approaches for integrating this technology between wide area and local area networks.
- NASA provided T3 services to two of its Grand Challenge Centers (Ames Research Center and Goddard Space Flight Center) through direct connection to NSFNET. In addition, service to several remote investigators was upgraded to T1 data rates.

- NASA launched its Advanced Communications Technology Satellite (ACTS).



Advanced Communications Technology Satellite (ACTS) deployed by the Space Shuttle.

- NIH and NSF funded 15 Medical Connections grants for academic medical centers and consortia to connect to the Internet.

- Five "gigabit testbeds" established by NSF and ARPA (described on page 9) became operational. In addition, a DOD-oriented testbed founded by ARPA focuses on terrain visualization applications.

- ARPA established a gigabit testbed in the Washington, DC area in cooperation with more than six other agencies in the area.

Projected FY 1994 Accomplishments

- Awards will be made to implement a new NSFNET network architecture (including network access points (NAPs), a routing arbiter, a very high speed backbone, and regional networks).

- Additional very high speed backbones will link HPCRCs (High Performance Computing Research Centers, described on pages 12-14).

- Connectivity for DOE's ESnet will grow to 27 sites.

- More universal and faster Internet connections for the research and education community

- Improved network information services and tools

Proposed FY 1995 Activities

- NSFNET — Implement new architecture (awards were made in FY 1994); implement very high speed backbone to NSF Supercomputer Centers; establish some additional high speed links for demanding applications

- DOE — Upgrade ESnet services to T3 and selected sites to 155 Mb/s; upgrade connectivity to Germany and Italy to T1 and to Russia to 128 Kb/s (kilobits per second or thousands of bits per second)

- NASA's AEROnet and NSI — Establish internal T3 and higher speed network backbone to five NASA centers

- Expand connectivity to schools (K-12 through university) — connectivity funded by NSF and NIH will reach a total of 1,500 schools, 50 libraries, and 30 medical centers; NASA's Spacelink computer information system for educators will be made available via the Internet; toll-free dial-up access will be provided to teachers without Internet access.

- NIH — Acquire gigabit (billions of bits per second) local networks for use with multiple parallel computers and as a backbone to enable development of the "Xconf" image conferencing system

- Integrate NOAA's more than 30 environmental data centers into the Internet through high speed connectivity and new data management tools

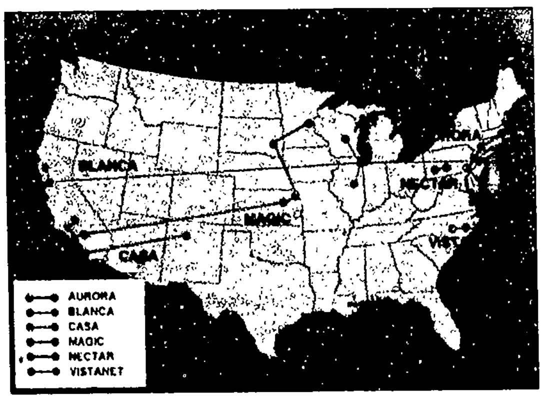
- Expand EPA connectivity to reach a substantial percentage of Federal, state, and industrial environmental problem-solving groups and test distributed computing approaches to complex cross-media environmental modeling

- Continue to support and improve information services such as the NSFNET Internet Network Information Center (InterNIC)

1.3. Gigabit Speed Networking R&D

New technologies are needed for the new breed of applications that require high performance computers and that are demanded by users across the U.S. These technologies must move more information faster in a shared environment of perhaps tens of thousands of networks with millions of users. Huge files of data, images, and videos must be broken into small pieces and moved to their destinations without error, on time, and in order. These technologies must manage a user's interaction with applications. For example, a researcher needs to continuously display on a local workstation output from a simulation model running on a remote high performance system in order to use that information to modify simulation parameters.

As these gigabit speed networks are deployed, the current barriers to more widespread use of high performance computers will be surmounted. At the same time, high speed workstations and small and mid-size scalable parallel systems will gain wider use.



HPCC-supported gigabit testbeds funded jointly by NSF and ARPA test high speed networking technologies and their application in the real world.

A teraflops (a trillion floating point operations per second) computing technology base needs gigabit speed networking technologies.

The HPCC Program is developing a suite of complementary networking technologies to take fullest advantage of this increased computational power. R&D focuses on increasing the speed of the underlying network technologies as well as developing innovative ways of delivering bits to end users and systems. These include satellite, broadcast, optical, and affordable local area designs.

The HPCC Program's gigabit testbeds are putting these technologies to the test in resource-demanding applications in the real world. These testbeds provide working models of the emerging commercial communications infrastructure, and accelerate the development and deployment of gigabit speed networks.

In FY 1994-1995, HPCC-funded research is addressing the following:

- ATM/SONET (Asynchronous Transfer Mode/Synchronous Optical Network) technology — "fast packet switched" cell relay technology (in which small packets of fixed size can be rapidly routed over the network) that may scale to gigabit speeds

- Interfacing ATM to HiPPI (High Performance Parallel Interface) and HiPPI switches and cross connects to make heterogeneous distributed high performance computing systems available at high network speeds

- All-optical networking

- High speed LANs (Local Area Networks)

- Packetized video and voice and collaborative workspaces (such as virtual reality applications that use remote instruments)

- Telecommuting

- Intelligent user interfaces to access the network

- Network management (for example, reserving network resources, routing information over the networks, and addressing information not only to fixed geographical locations but also to people wherever they may be)

- Network performance measurement technology (to identify bottlenecks, for example)

- Networking standards (such as for interoperability) and protocols (including networks that handle multiple protocols such as TCP/IP, GOSIP/OSI, and popular proprietary protocols)

Additional FY 1995 plans include completing DOE's high speed LAN pilot projects and providing select levels of production-quality video/voice teleconferencing capability. NASA and ARPA plan experiments in mitigating transmission delay to the ACTS satellite. NASA plans to extend terrestrial ATM networks to remote locations via satellite and to demonstrate distributed airframe/propulsion simulation via satellite.

1.4. Network Security

Network data security is vital to HPCC agencies and to many other users such as the medical and financial communities. FY 1994-1995 research is directed at incorporating security in the management of current and future networks by protecting network trunks and individual systems. Examples include:

- Joint ARPA/NSA projects in gigabit encryption systems for use with ATM

- Use of the ARPA-developed KERBEROS authentication system by DOE for distributed environment authentication and secure information search and retrieval

- Methods for certifying and accrediting information sent over the network

NSA is addressing the compatibility of DOD private networks with commercial public networks.

The rapid growth of networks and of the number of computers connected to those networks has prompted the establishment of incident response teams that monitor and react to unauthorized activities, potential network intrusions, and potential system vulnerabilities. Each team serves a specific constituency such as an organization or a network. One of the first such teams was CERT, the Computer Emergency Response Team, based at the Software Engineering Institute in Pittsburgh, PA. CERT was established in 1989 by ARPA in response to increasing Internet security concerns, and serves as a response team for much of the Internet. FIRST, the Forum of Incident Response and Security Teams, was formed under DOD, DOE, NASA, NIST, and CERT leadership. FIRST is a growing global coalition of response teams that alert each other about actual or potential security problems, coordinate responses to such problems, and share information and develop tools in order to improve the overall level of network security.

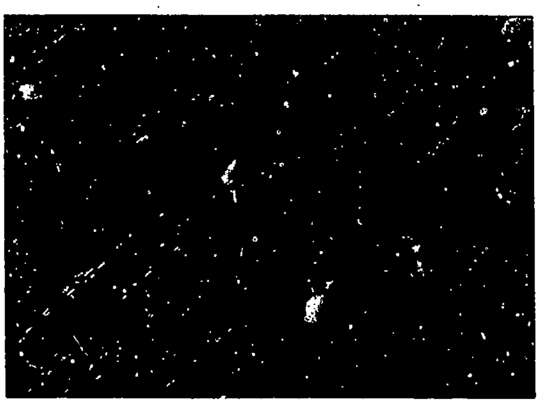
2. High Performance Computing Systems

At the beginning of the HPCC Program in 1991, few computer hardware vendors were developing scalable parallel computing systems, even though they acknowledged that traditional vector computers were approaching their physical limits. By 1993, all major U.S. vendors had adopted scalable parallel technology. Today, a wide range of new computing technologies is being introduced into commercial systems that are now being deployed at the HPCRCs, in industry, and in academia. These include the whole range of scalable parallel and traditional systems such as fine- and coarse-grained parallel architectures,

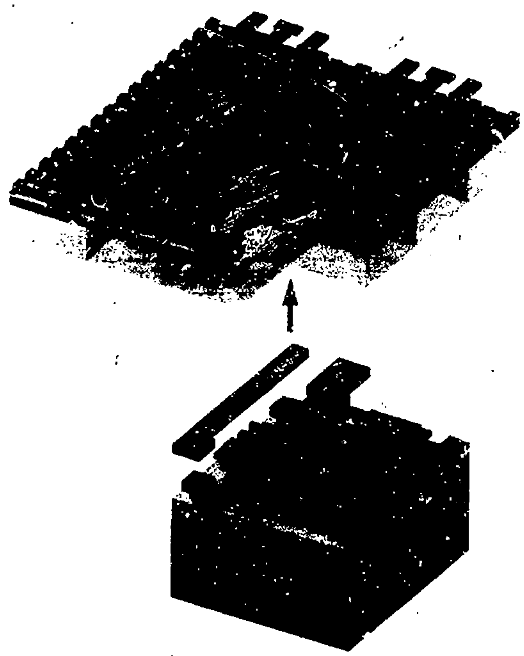
vector and vector/parallel systems, networked workstations with high speed interfaces and switches, and heterogeneous platforms connected by high speed networks. Some of these systems now scale to hundreds of gigaflops (billions of floating point operations per second). The HPCC Program is well on track toward meeting its FY 1996 goal of demonstrating the feasibility of affordable multipurpose systems scalable to teraflops (trillions of floating point operations per second) speeds.

The architectures of scalable systems — how the processors connect to each other and to memory, and how the memory is configured (shared or distributed) — vary widely. How these architectures communicate with storage systems such as disks or mass storage and how they network with other systems also differ.

In past years, the HPCC Program concentrated on the design and manufacture of high performance systems, including fundamental underlying components, packaging, design tools, simulations, advanced prototype systems, and scalability. ARPA is the primary HPCC agency involved in developing this underlying scalable systems technology, often cost-shared with vendors, for the high performance computing systems placed at HPCC centers across the country. Efforts are still devoted to developing the foundation for the next generation of high performance systems, including new system components that overcome speed and power limitations, scalable techniques to exploit mass storage systems, sophisticated design technology, and ways to evaluate system performance. Additional effort is now being devoted to developing systems software, compilers, and environments to enable a wide range of applications.



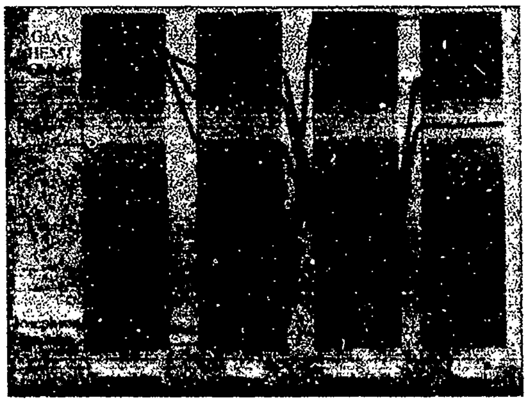
Simulation of the behavior of materials at the fundamental atomic scale (adsorption and diffusion of germanium on a reconstructed Si(100) surface). Simulated using the iPSC/860 hypercube and the Paragon XP/S-5 supercomputers.



Scaling of memory chip technology is essential to increase both speed and capacity of computer-based systems. This figure shows details of 16 memory cells in a high density 1 megabit Static Random Access Memory (SRAM) that were created and visualized using advanced model tools for integrated circuit and technology design developed at Stanford University. Each color represents a physical layer of material (grey-silicon, yellow-silicon oxide, pink-polysilicon, teal-local interconnect and blue-metal) which has been patterned using advanced lithography and etching techniques. The details of geometries and spacings between the various layers are critical in determining both the performance of the SRAM and its manufacturability. Solid geometry models and three-dimensional simulations of both materials interactions and electrical performance are invaluable in optimizing such high density chips.

(Figure Courtesy of Cypress Semiconductor)

The applications now running on the new systems handle substantially more data — both input and output — than on traditional systems. Graphical display is critical to analyzing these data quickly and effectively. For example, output from three-dimensional weather models must be displayed and overlaid with real-time data collected from networked instruments at remote observation stations. Hardware to handle this task well, such as workstations for scientific visualization, is part of a high performance computing environment.



Comparison of Josephson Junction technology with gallium arsenide and CMOS (complementary metal oxide semiconductor) technologies showing potential for dramatic improvements in performance with low power.

The HPCC Program develops and evaluates a variety of innovative technologies that have potential for future use beyond the next generation of systems. Included in these are superconductive devices. These devices have demonstrated blinding speed and exceptionally low power consumption at the chip level, but need to be scaled up to more complex components to be useful. If transferable to the system level, these devices would have major impact on computing and communications switching systems. NSA is developing a technology demonstration of a multigigabit per second 128x128 crossbar switch that is potentially expandable to 1000x1000 at very low power. If successful, the technology will be evaluated in a system level computing application.

3. High Performance Computing Research Centers (HPCRCs)

HPCRCs are a cornerstone of the HPCC Program. HPCRCs are the home of a variety of systems: early prototypes, small versions of mature systems, full-scale production systems, and advanced visualization systems. The current production systems, capable of hundreds of gigaflops of sustained throughput, will be succeeded by teraflops systems. These systems are being used on Grand Challenge class applications that cannot be scaled down without modifying the problem being addressed or requiring unacceptably long execution times. The largest of these applications are being run on multiple high performance computers located around the country and networked in the gigabit testbeds.

An interdisciplinary group of experts meets at these centers to address common problems. These include staff from the HPCRCs themselves, hardware and software vendors, Grand Challenge applications researchers, industrial affiliates that want to develop industry-specific software, and academic researchers interested in advancing the frontier of high performance computing. Funding is heavily leveraged, with HPCC agencies often contributing discretionary funds, hardware vendors providing equipment and personnel, and affiliate industries paying their fair share. Industrial affiliation offers a low risk environment for exploring and ultimately exploiting HPCC technology. Two of these industrial affiliations are:

- The Oil Reservoir Modeling Grand Challenge in which more than 20 companies and several universities participate
- The High Performance Storage System Project in which more than 12 companies and national laboratories participate

Production-quality operating systems and software tools are developed at these centers, thereby removing barriers to efficient hardware use. Applications software tailored to high performance systems is developed by early users, many of whom access these systems over the Internet, and increasingly over the gigabit

testbeds, from their workstations. Production-quality applications software is often first run on HPCRC hardware. The wide range of hardware at HPCRCs makes them ideal sites for developing the conventions and standards that enable and test interoperability, and for benchmarking systems and applications software.

Production-quality applications software often is run first on computing systems at HPCRCs.

The major HPCRCs are:

NSF Supercomputer Centers —

- Cornell Theory Center, Ithaca, NY
- National Center for Supercomputer Applications, Champaign-Urbana, IL
- Pittsburgh Supercomputer Center, Pittsburgh, PA
- San Diego Supercomputer Center, San Diego, CA

Tens of thousands of users from more than 800 institutions in 49 states and 111 industrial partners have computed on systems at the NSF centers. Currently there are 8,000 users and 78 partners. The centers are developing a National Metacenter Environment in which a user will view multiple centers as one. The National Center for Atmospheric Research (NCAR) in Boulder, CO, also receives HPCC funds.

NSF Science and Technology Centers —

- Center in Computer Graphics and Scientific Visualization —Brown University, Providence, RI; CalTech, Pasadena, CA; Cornell University, Ithaca, NY; University of North Carolina, Chapel Hill, NC; University of Utah, Salt Lake City, UT
- Center for Research on Parallel Computation, Rice University, Houston, TX

NASA Centers —

- Ames Research Center, Mountain View, CA
- Goddard Space Flight Center, Greenbelt, MD

DOE Centers —

- Los Alamos National Laboratory, Los Alamos, NM
- National Energy Research Supercomputer Center, Lawrence Livermore National Laboratory, Livermore, CA
- Oak Ridge National Laboratory, Oak Ridge, TN

The DOE centers accommodate more than 4,000 users from national laboratories, industry, and academia.

Major systems at HPCRCs include one or more of each of the following (the number of processors in the largest machine at an HPCRC is shown in parentheses):

- Convex
  - C3880 (8 vector processors)
- Cray Research
  - C90 (16 vector processors)
  - T3D (512 processors)
  - YMP (8 vector processors)
- Digital Equipment Corp.
  - Workstation Cluster
- Hewlett-Packard

- H-P Workstation Cluster

- IBM
  - ES9000/900 (6 vector processors)
  - PVS
  - SP1 (512 processors)
  - Workstation Cluster

- Intel
  - iPSC 860 (64 processors)
  - Paragon (512 processors)

- Kendall Square Research
  - KSR 1 (160 processors)

- MasPar
  - MasPar 2 (16,000 processors)
  - MasPar MP-1 (16,000 processors)

- nCube
  - nCUBE2

- Thinking Machines
  - CM2 (32,000 processors)
  - CM5 (1,024 processors)

Smaller versions of some of these scalable high performance systems have been installed at more than a dozen universities. The HPCRCs also use a variety of scientific workstations, such as those from Silicon Graphics and Sun Microsystems, for numerous tasks.

FY 1995 Plans

- NSF will install new scalable parallel hardware and hardware upgrades, enhance Metacenter resources, and establish several more regional alliances.

- DOE will install two different 150 gigaflop machines at two sites.

- NASA will establish a prototype high performance computing facility comparable in nature but not in performance to the ultimate teraflops facility. It will be configured with advanced high performance machines, early systems or advanced prototypes of important storage hierarchy subsystems, and sufficient advanced visualization facilities to enable system scaling experiments. NASA Grand Challenge researchers in Federal laboratories, industry, and academia will access these advanced systems using the Internet and gigabit speed networks. These researchers will provide a spectrum of experiments for scalability studies. Prototype systems and subsystem interfaces and protocol standards will be established and evaluated, accelerating the understanding of the character of future teraflops computing systems.

- NOAA will acquire a high performance computing system for its Geophysical Fluid Dynamics Laboratory at Princeton, NJ to develop new scalable parallel models for improved weather forecasting and for improved accuracy and dependability of global change models.

- EPA will acquire a scalable parallel system to support more complex multipollution and cross-media (combined air and water) impact and control assessments.

4. Software

HPCC Program software development efforts were originally planned to address the Grand Challenges associated with agency missions. As the Program has matured, these efforts have been expanded to support the needs of industry and improve U.S. competitiveness.

The range of applications software being developed under the Program will assure that high performance computing systems can be broadly useful to the American economy. Now these systems must be made easier to use. Experienced software developers and applications researchers, many at or connected to HPCRCs, are working to meet these needs.

It took a decade to develop a collection of efficient and robust software for vector machines, and it is widely believed that it will take at least that long for parallel systems. Performance is dramatically improving on these systems, due to new algorithms, systems, and experienced people. Continued software work is needed to realize their full potential. The user community is growing so fast that demand for computer time on these systems exceeds supply.

4.1. Systems Software and Software Tools

The high performance computing environment model involves workstation interaction with high performance systems. This approach makes it possible for users to almost transparently access higher performance machines as problem size grows and the software on these machines matures.

This environment is fundamentally and profoundly different from and more complicated than traditional computing environments. Much of the systems software and software tools for parallel computing has been redesigned and rewritten to take advantage of the theoretical benefit of parallelism and enhance user productivity:

- Operating systems manage dozens to thousands of processors, their memory, and networked heterogeneous systems.

- New programming languages allow straightforward expression of parallel constructs.

- Mechanisms express bit manipulation in a parallel environment.

- Precompilers automatically optimize and parallelize.

- Compilers generate instructions to distribute the computation across the processors, memory, and networks.

- Debuggers help developers find coding mistakes.

- Performance monitors and displays assist developers in identifying where optimization efforts might best be spent, facilitate development of dynamic resource management strategies, and are used to evaluate different architectures (in part to recommend changes in vendor-provided utilities).

- Software manages the parallel computer's input from and output to other computers, distributed hierarchical mass storage, and data collection hardware such as satellites.

- New scientific visualization methods and software display the large amounts of data used and produced by high performance computers.

- Software tools enable public dissemination of advanced software and documentation.

- Production environment tools schedule jobs, multitask (run several jobs simultaneously), implement quotas, and provide "checkpoint and restart" and on-line documentation.

Evolving conventions and standards enable developers to transport software to different architectures and make it look the same to users. High Performance Fortran (HPF) is an example. Coordinated by the Center for Research on Parallel Computation at Rice University, the HPF Forum is a coalition of government, the high performance computer industry, and academic groups that is developing standard extensions to Fortran on vector processors and massively parallel SIMD (Single Instruction Multiple Data) and MIMD (Multiple Instruction Multiple Data) systems.

The software development process is evolutionary — tool developers debug codes and make them more efficient while users and their applications place new demands on these tools, resulting in further improvements, refinements, speed-ups, and increased user-friendliness. Accelerating this cycle is one objective of the HPCC Program.

4.2. Scientific Computation Techniques

The development and analysis of fundamental algorithms for use in computational modeling represented in the Grand Challenges are as critical to realizing peak performance of scalable systems as are improvements in hardware. Such research includes studies of algorithms applicable to a wide range of parallel machines as well as those that take advantage of the strengths of specific architectures.

These algorithms address both numerical computation (where arithmetic calculations predominate) and non-numeric (where finding and moving data rule). Widely used numerical computations include multidimensional fast Fourier transforms, fast elliptic and Riemann solvers in partial differential equations, and numerical linear algebra. The latter includes manipulating vectors and matrices, solving systems of linear equations, and computing eigenvalues and eigenvectors. Efficient algorithms attuned to specialized matrix structure (for example, dense or sparse) are especially sought. Numerical linear algebra is an area that was assumed to be well understood, having been subject to substantial research for vector processors. Somewhat surprisingly, algorithmic breakthroughs made as these codes were ported to parallel systems have also resulted in improved performance on vector processors.

These computations are common to so many applications that they are developed by experts to attain maximal efficiency, and their implementations are included in general-purpose reusable software libraries. When these libraries are updated with the more efficient software, users immediately observe faster execution times for their applications. Several HPCC agencies are building such libraries and making them widely available.

4.3. Grand Challenge Applications

The successful use of scalable parallel systems for Grand Challenge applications requires designing new hardware, developing new systems software and software tools, and integrating these with the idealized setting of mathematics and with the complex environment of real world applications and real world users. The maturing HPCC Program is placing increased emphasis on facilitating this integration. For example, the Program sponsored the first "Workshop and Conference on Grand Challenge Applications and Software Technology" in May 1993. Some 250 people representing 34 Grand Challenge teams evaluated progress and planned future activities. A second workshop is scheduled for 1995.

As this new software becomes more efficient, stable, and robust, applications researchers are porting their software to the new parallel systems more quickly and are achieving faster run times. They are also obtaining more realistic results by taking advantage of the faster speeds, larger memory, and the opportunity to add complexity, which was not possible before the new architectures became available. This realism comes through:

- Higher resolution (for example, modeling a beat of the human heart at time steps of a tenth of a second instead of each second, and at every hundredth centimeter rather than every centimeter)

- Faster execution times (for example, models that took days of execution time now take hours, enabling researchers to explore a wider range of parameters and time scales — 100 year climate models can now be executed in the same time it used to take for 10 year models)

- More realistic physics — for example, including in weather models the physics that better model the effects of clouds

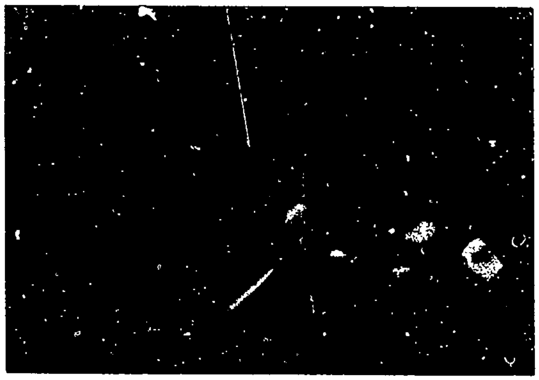
- More realistic models (for example, one "multidisciplinary" model combining separate atmosphere and ocean models, or one combining "single discipline" air and water pollution models)

Entirely new approaches are being developed for cases in which existing models or their algorithmic components are inappropriate for parallel architectures.

Researchers are now benchmarking Grand Challenge applications on a variety of high performance systems to determine not only where they run fastest but also the reasons why, since demand for processors, memory, storage, and communication all affect speed. These researchers work closely with systems software and software tool developers, and they communicate intensively with hardware vendors. This feedback loop results in a wide range of improvements in high performance software and hardware.

As Grand Challenge applications prove the mettle of scalable parallel architectures, commercial software vendors are becoming more active in moving their software to these new machines. The success of commercial applications software is crucial to the success of the high performance computing industry.

NSF, with assistance from ARPA, has funded 16 Grand Challenge Applications Groups for three years beginning in FY 1993 or FY 1994. DOE has funded nine multi-year Grand Challenge projects, some jointly with other DOE programs, HPCC agencies, and industry. NASA, NIH, NIST, NOAA, and EPA have similar Grand Challenge groups. These groups are addressing problems in the following areas.



Simulation of a tiltrotor aircraft (V-22 Osprey) during takeoff. Shown are streaklines, rendered as smoke and computed using UFAT (Unsteady Flow Analysis Toolkit), a new time-dependent particle tracing code.

Aircraft

Improved and more realistic models and computer simulations of aerospace vehicles and propulsion systems are being developed. These will allow for analysis and optimization of designs over a broad range of vehicle classes, speeds, and physical phenomena, using affordable, flexible, and fast computing resources. Development of parallel benchmarks is an area of intensive activity. These applications are computationally unrealistic with traditional computing technology. NASA's Computational Aeroscience Grand Challenges include the High Speed Civil Transport, Advanced Subsonic Civil Transport, the High-Performance Aircraft, and Rotorcraft. This clearly is an area of significant mutual benefit to both the HPCC Program and other major NASA programs.

In addition, NSF has funded a Grand Challenge Applications Group to address fundamental problems in coupled field problems and geophysical and astrophysical fluid dynamics turbulence.

Computer Science

NSF has funded Grand Challenge Applications Groups in:

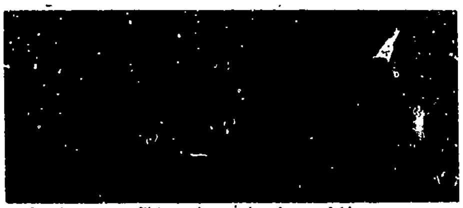
- High performance computing for learning
- Parallel I/O (input/output) methods for I/O-intensive Grand Challenge applications

Energy

DOE's Grand Challenge projects are exploring:

- Mathematical combustion modeling — developing adaptive parallel algorithms for computational fluid dynamics and applying them to combustion models
- Quantum chromodynamics calculations — developing lattice gauge algorithms on massively parallel machines for high energy physics and particle physics applications
- Oil reservoir modeling — constructing efficient parallel algorithms to simulate fluid flow through permeable media

(a) Beginning of the injection phase; t = 0.560 ms.



(b) Inlet jet prior to collision with stagnation plate; t = 1.64 ms.

(c) Vortex ring formed by flow separation at the edge of the stagnation plate ; t = 2.66 ms.

(d) Peak of injection phase: t = 4.07 ms.

Model showing initiation of water heater combustion.

- The numerical Tokamak project — developing and integrating particle and fluid plasma models on massively parallel machines as part of the multidisciplinary study of Tokamak fusion reactors

Environmental Monitoring and Prediction

The environmental Grand Challenges include weather forecasting, predicting global climate change, and assessing the impacts of pollutants. High performance computers allow better modeling of the Earth and its atmosphere, resulting in improved guidance for weather forecasts and warnings, and improved global change models.

High resolution local and regional weather models are being incorporated into larger national and global weather forecasting counterparts. Several of these models are used widely by researchers to investigate and monitor the behavior of the atmosphere through numerical simulation. NOAA scientists are redesigning some of these models to take full advantage of new scalable systems. Some global models are "community models," used by researchers worldwide to compare results with observations and with other related models, and to evaluate performance. For example, a set of modular, portable benchmark codes is being developed and evaluated on several scalable systems and networked workstations at the Boulder Front Range Consortium. Funding for this work comes from ARPA's National Consortium for High Performance Computing, NOAA's Forecast Systems Laboratory, the NSF-funded National Center for Atmospheric Research, and the University of Colorado. Users of these improved models include the Federal Aviation Administration and the National Weather Service.

Models of the atmosphere and the oceans are being rewritten in modular form and transported to several large parallel systems; funding sources include DOE's Los Alamos National Laboratory, NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), and the Navy. A much greater level of detail is now possible — local phenomena such as eddies in the Gulf of

Mexico are being modeled, which allows for better warning of weather emergencies and improved design of equipment such as oil rigs.

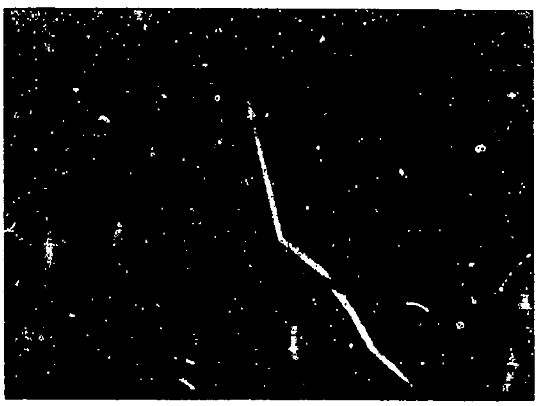
Separate air and water quality models are being combined into a single model which is being transported to a variety of massively parallel systems where benchmarks are being used to evaluate performance. These models are needed to assess the impact of pollutant contributions from multimedia sources and to ensure adequate accuracy and responsiveness to complex environmental issues. Nutrient loading in the Chesapeake Bay and PCB transport in the Great Lakes are being targeted beginning in FY 1994.

In FY 1995, complexities such as aerosols, visibility, and particulates will be added; entire environmental models will be integrated into parallel computing environments with a focus on emissions modeling systems and integration with Geographical Information Systems.

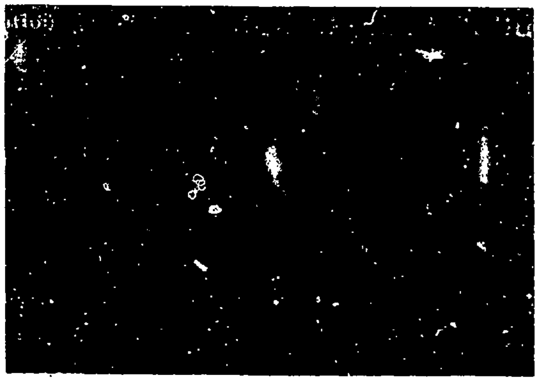
EPA will acquire a large massively parallel system to be used initially for this research. A transition to an operational computing resource that supports improved environmental assessment tools is planned.

NSF has funded Grand Challenge Applications Groups to address fundamental problems in:

- Large scale environmental modeling



The track of Hurricane Emily predicted by NOAA's GFDL (yellow) and the observed track (orange).



Model prediction of the amount of lead, a toxic pollutant, deposited by atmospheric processes during August 1989.

- Adaptive coordination of predictive models with experimental observations
- Earthquake ground motion modeling in large basins
- High performance computing for land cover dynamics
- Massively parallel simulation of large scale, high resolution ecosystem models

DOE's Grand Challenge projects are exploring:

- Computational chemistry — parallelize codes and develop modeling systems for critical environmental problems and remediation methods
- Global climate modeling — numerical studies with large atmosphere and ocean general circulation models
- Groundwater transport and remediation — develop comprehensive multiphase, multicomponent groundwater flow and transport software

NASA has funded Grand Challenge research teams in:

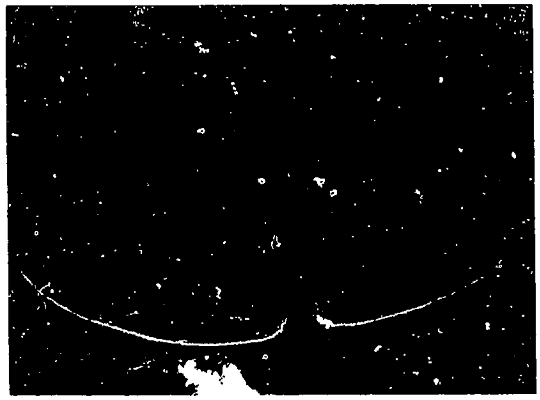
- Atmosphere/ocean dynamics and trace chemistry
- Climate models
- Four-dimensional data assimilation for massive Earth system data analysis
- Discovering knowledge in geophysical databases

The environmental monitoring and prediction Grand Challenge enables better decision making by government and industry on issues that affect both the economy and the environment.

Molecular Biology and Biomedical Imaging

FY 1994 NIH accomplishments include:

- Development and field testing of the Diagnostic X-ray Prototype Network (DXPnet), a nationwide radiology research image system
- Deployment of Network Entrez, an Internet-based client-server system that enables integrated searching of DNA and protein sequences and the medical literature linked to those sequences
- Usage of the Internet-based BLAST (Basic Local Alignment Sequence Tool) for advanced biological similarity searching reached 3 million queries per year.
- Improved understanding of heart function through the three-dimensional simulation of a single heartbeat (this required 150 hours on the fastest Cray and received a Smithsonian Award)
- First simulation of an entire biological membrane including all lipid and protein components, enabling better understanding of the mechanism of inflammation of tissues in diseases such as asthma and arthritis (collaborative work with Eli Lilly)
- Order of magnitude speedups in several molecular analysis algorithms
- New software for coupling vector processors with massively parallel systems, providing a new avenue for molecular dynamics calculations
- New algorithms for registration and rendering of three-dimensional images from two-dimensional clinical images and micrographs
- Assistance in the design of new drugs to inhibit HIV replication
- Further elucidation of the structure of the herpes virus using high performance computing to obtain three-dimensional images from electron micrographs
- Determined the three-dimensional structure of several proteins by using a genetic algorithm approach to automate the spectral assignment task in NMR spectroscopy



A closeup view looking down on the aortic valve in a computational model of blood flow in the heart. The model was developed by Charles Peskin and David McQueen of New York University and run on the Pittsburgh Supercomputing Center's Cray C90.

- Developed parallel molecular dynamics simulation software to determine the effects of hydration on protein structure
- Developed benchmark codes for evaluating high performance systems

FY 1995 NIH plans include:

- Expand research in algorithms for real-time acquisition and processing of multi-model medical images for use in telemedicine and virtual environments for surgery
- Develop new algorithms and software for receptor-based drug design; study basic mechanisms of receptor structure and function; and develop software to model specific populations at risk for disease
- R&D in medical image processing for basic research, clinical research, and health care delivery
- Support development of telemammography, addressing high resolution, wide field-of-view displays and high performance, low cost networks for image transmission

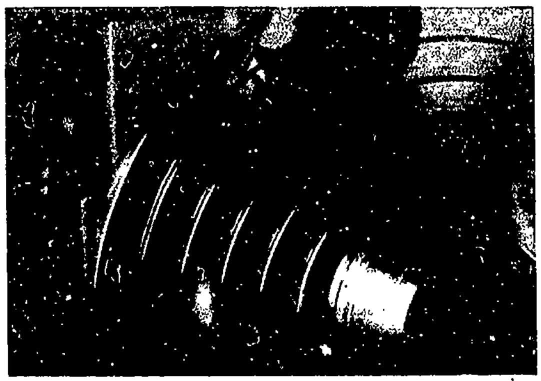
NSF has funded Grand Challenge Applications Groups in:

- Biomolecular design
- Imaging in biological research
- Advanced computational approaches to biomolecular modeling and structure determination
- Understanding human joint mechanisms through advanced computational models

DOE's Grand Challenge projects are exploring computational structural biology — understanding the components of genomes and developing a parallel programming environment for structural biology.

Product Design and Process Optimization

Beginning in FY 1995, NIST will develop new high performance computing tools for applying computational chemistry and physics to the design, simulation, and optimization of efficient and environmentally sound products and manufacturing processes. Initial focus will be on the chemical process industry, microelectronics industry, and biotechnology manufacturing. Existing software for molecular modeling and visualization will be adapted for distributed, scalable computer architectures. New computational methods for first-principles modeling and analysis of molecular and electronic structure, properties, interactions and dynamics will be developed. Macromolecular structure, molecular recognition, nanoscale materials formation, reacting flows, the automated analysis of complex chemical systems, and electronic and magnetic properties of thin films will receive particular emphasis.



Diamond-tool turning and grinding machines are the epitome of precision manufacturing tools, capable of machining high precision optical finishes without additional polishing (such as on this copper mirror for a laser system). NIST researchers and their industrial partners are developing methods for monitoring and controlling diamond turning machines to improve the precision and production of highly efficient optics such as mirrors for laser welders.

NSF has funded a Grand Challenge Applications Group to address fundamental problems in high capacity atomic-level simulations for the design of materials.

A DOE Grand Challenge project involves first-principles simulation of materials properties using a hierarchy of increasingly more accurate techniques that exploit the power of massively parallel computing systems.

Space Science

NASA's Earth and Space Science projects support research in:

- Large scale structure and galaxy formation
- Cosmology and accretion astrophysics
- Convective turbulence and mixing in astrophysics
- Solar activity and heliospheric dynamics

NSF has funded Grand Challenge Applications Groups to address fundamental problems in:

- Black hole binaries: coalescence and gravitational radiation
- The formation of galaxies and large-scale structure
- Radio synthesis imaging

5. Technologies for the NII

The HPCC Program is helping to develop much of the technology underlying the NII in order to address National Challenge problems of significant social and economic impact. This technology includes advanced information services, software development environments, and user interfaces:

5.1. Information Infrastructure Services

These services provide the underlying building blocks upon which the National Challenges can be constructed. They provide layers of increasing intelligence and sophistication on top of the "communications bitways." These include:

- Universal network services. These are extensions to existing Internet technology that enable more widespread use by a much larger user population. They include techniques for improved ease-of-use, "plug and play" network interoperation, remote maintenance, exploitation of new "last mile" technologies such as cable TV and wireless, management of hybrid/asymmetric network bandwidth, and guaranteed quality of service for continuous media streams such as video.

- Integration and translation services. These support the migration of existing data files, databases, libraries, and software to new, better-integrated models of computing such as object-oriented systems. They provide mechanisms to support continued access to older "legacy" forms of data as the models evolve. Included are services for data format translation and interchange as well as tools to translate the access portions of existing software. Techniques include "wrappers" that surround existing elements with new interfaces, integration frameworks that define application-specific common interfaces and data formats, and "mediators" that extend generic translation capabilities with domain knowledge-based computations, permitting abstraction and fusion of data.

- System software services. These include operating system services to support complex, distributed, time-sensitive, and bandwidth-sensitive applications such as the National Challenges. They support the distribution of processing across processing nodes within the network; the partitioning of the application logic among heterogeneous nodes based on their specialized capabilities or considerations of asymmetric or limited interconnection bandwidth; guaranteed real-

time response to applications for continuous media streams; and storage, retrieval, and I/O capabilities suitable for delivering large volumes of data to very large numbers of users. Techniques include persistent storage, programming language support, and file systems.

- Data and knowledge management services. These include extensions to existing database management technology for combining knowledge and expertise with data. These include methods for tracking the ways in which information has been transformed. Techniques include distributed databases, mechanisms for search, discovery, dissemination, and interchange, aggregating base data and programmed methods into "objects," and support for persistent object stores incorporating data, rules, multimedia, and computation.

- Information security services. These help in protecting the security of information, enhancing privacy and confidentiality, protecting intellectual property rights, and authenticating information sources. Techniques include privacy-enhanced mail, methods of encryption and key-escrow, and digital signatures. Also included are techniques for protecting the infrastructure (such as authorization mechanisms and firewalls) against intrusion attacks (such as by worms, viruses, and trojan horses).

- Reliable computing and communications services. These include services for non-stop, highly reliable computer and communications systems operating 24 hours a day, 7 days a week. The techniques include mechanisms for fast system restart such as process shadowing, reliable distributed transaction commit protocols, and event and data redo logging to keep data consistent and up-to-date in the face of system failures.

5.2. Systems Development and Support Environments

These will provide the network-based software development tools and environments needed to build the advanced user interfaces and the information-intensive National Challenges themselves. These include:

- Rapid system prototyping. These consist of software tools and methods that enable the incremental integration and cost effective evolution of software systems. Technologies include tools and languages that facilitate end-user specification, architecture design and analysis, and component reuse and prototyping; testing and on-line configuration management tools; and tools to support the integration and interoperation of heterogeneous software systems.

- Distributed simulation and synthetic environments. These software development environments support the creation of synthetic worlds that can integrate real as well as virtual objects that have both visual and computational aspects. Methods include geometric models and data structures; tools for scene creation, description, and animation; integration of geometric and computational models of behavior into a combined system description; and distributed simulation algorithms.

- Problem solving and system design environments. These provide automated tools for software and system design that are flexible and can be tailored to individual needs. Examples include efficient algorithms for searching huge planning spaces; more powerful and expressive representations of goals, plans, operators, and constraints; and efficient scheduling and resource allocation methods. The effects of uncertainty and the interactions of goals will be addressed.

- Software libraries and composition support. Common architectures and interfaces will increase the likelihood of software reuse across different computational models, programming languages, and quality assurance. By developing underlying methodology, data structure, data distribution concepts, operating systems interfaces, synchronization fea-

tures, and language extensions, scalable library frameworks can be constructed.

- Collaboration and group software. These tools support group cooperative work environments that span time and space. They will make it possible to join conferences in progress and automatically be brought up to date by agents with memory. Methods include network-based video conferencing support, shared writing surfaces and "live boards," document exchange, electronic multimedia design notebooks, capturing design history and rationale, agents or intermediaries to multimedia repositories, and version and configuration management.

5.3. Intelligent Interfaces

Many of the National Challenge applications require complex interfacing between humans and intelligent control systems and sensors, and among multiple control systems and sensors. These applications must understand their environment and react to it. High level user interfaces are needed to satisfy the many different requirements and preferences of vast numbers of citizens who will interact with the NII.

- Human-computer interface. A broad range of integrated technologies will allow humans and computers to interact effectively, efficiently, and naturally. Technologies will be developed for speech recognition and generation; graphical user interfaces will allow rapid browsing of large quantities of data; user-sensitive interfaces will customize and present information for particular levels of understanding; people will use touch, facial expressions, and gestures to interact with machines; and these technologies will adapt to different human senses and abilities. These new integrated, real-time communication modalities will be demonstrated in multimedia, multi-sensory environments.

- Heterogeneous database interfaces. Methods to integrate and access heterogeneously structured databases composed of multi-formatted data will be developed. In a future NII's information dissemination environment, a user could issue a query that is broadcast to appropriate databases and would receive a timely response translated into the context of the query. Examples of multi-formatted data include ASCII text, data that are univariate (such as a one-dimensional time series) or multivariate (such as multi-dimensional measurement data), and time series of digital images (such as a video).

- Image processing and computer vision. Images, graphics, and other visual information will become more useful means of human-computer communication. Research will address the theory, models, algorithms, architectures, and experimental systems for low level image processing through high level computer vision. Advances in pattern recognition will allow automated extraction of information from large databases such as digital image databases. Emphasis is placed on easily accessing and using visual information in real-world problems in an environment that is integrated and scalable.

- User-centered design tools/systems. New models and methods that lead to interactive tools and software systems for user-centered activities such as design will be developed. Ubiquitous, easy-to-use, and highly effective interactive tools are emphasized. A new research area is user-friendly tools that combine data-driven and knowledge-based capabilities.

- Virtual reality and telepresence. Tools and methods for creating synthetic (virtual) environments to allow real-time, interactive human participation in the computing/communication loop will be addressed. Participation can be through sensors, effectors, and other computational resources. In support of National Challenge application areas, efforts will focus on creating shared virtual environments that can be accessed and manipulated by many users at a distance.

6. National Challenges

These are large-scale, distributed applications of high social and economic impact that contain an extensive information-processing component and that can benefit greatly by building an underlying information infrastructure. National Challenges to be addressed by the HPCC Program in FY 1994 and FY 1995 include:

Digital Libraries

A digital library is the foundation of a knowledge center without walls, open 24 hours a day, and accessible over a network. The HPCC Program supports basic and strategic digital libraries research and the development and demonstration of associated technologies. These technologies are used in all of the other National Challenge applications.

Beginning in FY 1994, the Program will support the following R&D, much of it funded by a joint NSF/ARPA/NASA "Research in Digital Libraries" initiative:

- Technologies for automatically capturing data of all forms (text, images, speech, sound, etc.), generating descriptive information about such data (including translation into other languages), and categorizing and organizing electronic information in a variety of formats.

- Advanced algorithms and intelligent interactive Internet-based tools for creating and managing distributed multimedia databases and for browsing, navigating, searching, filtering, retrieving, combining, integrating, displaying, visualizing, and analyzing very large amounts of information that are inherently in different formats. These databases are frequently stored on different media that are distributed among heterogeneous systems across the Nation and around the world. Research will also address standards that enable interoperability.

NOAA will provide Internet-based access to and distribution of remote sensing imagery and other satellite products from its geostationary and polar orbiting operational environmental remote sensing satellites. NASA will provide access to other remote sensing images and data over the Internet and the gigabit testbeds. This includes making observational data from satellites available to state and local governments, the agriculture and transportation industries, and to libraries and educational institutions.

NSA will develop a prototype environment of the future in which a user, an application developer, and a data administrator each sees an integrated information space in terms directly meaningful and accessible to them, rather than as a collection of relatively unintelligible, difficult-to-access databases.

Crisis and Emergency Management

Large-scale, time-critical, resource-limited problems such as managing natural and man-made disasters are another vital National Challenge. Effective management involves the use of command, control, communications, and intelligence information systems to support decision makers in anticipating threats, formulating plans, and executing these plans through coordinated response. Many other National Challenge projects provide information and information management tools for use in crisis and emergency management. HPCC efforts include ARPA's research projects on ubiquitous data communications infrastructure in the face of disasters, including the timely development and transmission of plans to operational units, exploitation of technical and human sources of information, and input to command. NOAA plans to make available environmental warnings and forecasts and other relevant information to support emergency management through the Internet. In FY 1994, NSF initiated a program to support research leading to development of information infrastructure technologies that can be integrated into the civil infrastructure, including transportation, water quality, safety of waste removal, and access to energy sources.

Education and Lifelong Learning

HPCC support for this National Challenge involves making HPCC technologies a resource for the Nation's education, training, and learning systems for people of all ages and abilities nationwide. The NII approaches this challenge from several directions:

- Distance learning will bring specialized resources in a timely manner to geographically widespread students.
- Teacher training and coordination enhances the resources available to teachers at all educational levels.
- Students throughout the country will have access to information and resources previously only available at research and library centers.
- Lifelong learning provides educational opportunities to populations regardless of age or location.
- Digital libraries will make information available throughout the network — both for professionals as well as students at all levels.

The HPCC Program is providing network access and conducting pilot projects that demonstrate HPCC technologies for improving learning and training and that can be scaled to nationwide coverage. A program in networking infrastructure for education was begun by NSF in FY 1994. On-going K-12 programs in science, engineering, and biomedical and health applications are conducted by almost all HPCC agencies.

Electronic Commerce (EC)

This National Challenge integrates communications, data management, and security services to allow different organizations to automatically exchange business information. Communications services transfer the information from the originator to the recipient. Data management services define the interchange format of the information. Security services authenticate the source; verify the integrity of the information received; prevent disclosure by unauthorized users; and verify that the information was received by the intended recipient. Electronic commerce applies and integrates these services to support business and commercial applications such as electronic bidding, ordering and payments, and exchange of digital product specifications and design data.

ARPA will develop a common underlying infrastructure for authentication, authorization, accounting and banking services, usage metering, and fee-for-access within networks and distributed systems. ARPA is also developing mechanisms for active commerce that will seek out qualified bidders on behalf of customers, based on extensive knowledge of the bidders capabilities and the customers needs.

Beginning in FY 1995, NIST will collaborate with industry to develop and apply technologies that enable electronic commerce in general, with initial emphasis on the manufacturing of electronic and mechanical components and subsystems. The agency will conduct R&D in security services and establish facilities to support interoperability testing.

Energy Management

Oil consumption, capital investment in power plants, and foreign trade deficits all benefit from improved management of energy demand and supply. Beginning in FY 1994, DOE and the power utilities will document and assess the tools and technologies needed to implement the National Challenge of energy demand and supply management. They will also document the expected economic benefits and identify policy or regulatory changes needed so that the utilities can participate in the deployment of the NII.

Environmental Monitoring and Waste Minimization

Improved methods and information will dramatically increase the competitiveness of U.S. companies in the world's $100 billion per year envi-

One Giant Leap . . . Networks: Where Have You Been All My Life?

Midway through my junior year at New Hanover High School in Wilmington, North Carolina, an experience began for me that has re-routed the path of my entire education and learning adventures. I, and three other students, won a national scientific computing contest called SuperQuest, sponsored by the Cornell University and the National Science Foundation. SuperQuest was no ordinary science fair -- rather, it was a "take a giant leap outside of your mind" contest. It was a fortuitous opportunity for us high schoolers. Our sudden introduction to the world of high performance computers included IBM RISC clusters, an ES/9000 vector processor, and a KSR parallel processor.

One of the greatest benefits of participating in the SuperQuest program has been my exposure to computer networks and telecommunications. I delved into the online world for my first time before we had won, when the team and I were constructing a science project the SuperQuest judges might deem a winner. We spent just a semester reaching consensus on the topic! Each of us had ideas -- from investigating mag-lev trains, to orb spiderwebs, to the pitching of a baseball. Which of these were within our capability? And which should we perhaps leave to the Princeton researchers? We turned to the Internet to gather the advice and experience of more knowledgeable folks. Our first action was to post questions on as many science bulletin boards and online services as possible. The two we frequented were the SuperQuest homebase at the Cornell Theory Center, and the High Performance Computing network (HPC Wire) in Colorado. Both were the ideal sources to check the feasibility of modeling an orb spider web or the flight of a baseball on a supercomputer. Sometimes we received answers in a day -- and sometimes within an hour. We were wowed not only by the speed of the knowledge transfer, but also, by the altruism of the network community. Through our communications, we were able to quickly focus on the orb spider web as our project. It was within our scope.

In the archaic tradition of our 12 years of schooling, we trekked to the local library to research spider webs. This proved to be time consuming. One of our teachers introduced us to WAIS, an Internet indexed database search function. Ecstasy! We sat with him as he logged onto the net from his desktop PC, called up WAIS, and ordered it to do both a worldwide search of indexes with the words "spider" or "web" in them, and a cross-reference follow-up. Within 20 minutes, the net had spewed 20 pages of information sources. We were filled with the the sudden comprehension of the scientific process -- the gathering of data and the elimination of possibilities.

As part of the SuperQuest prize, we attended a three-week summer seminar at the Cornell Theory Center. There we were introduced to LAN networks and file-sharing, mainframes and X-terminals, and the minute details of the Internet. Thus, we could suddenly access the libraries of each of the seven schools at Cornell, as well as data from specialized projects such as the synchrotron and recent biomedical research. Again, the process of gathering data was accomplished primarily through using computer communications.

Upon our return home, we were able to use our Internet connection (which was another SuperQuest reward) to continue our research and also access the supercomputer facilities back at Cornell After two months of a maniacal pace, and with our interim report mailed, we decided to take a week-long break. However, I found myself drawn to the computer --there were so many interesting things to explore -- and I was so curious. I logged into "Sunsite" at the University of North Carolina at Chapel Hill and began browsing archives, just for the fun of it. I pulled up a picture of an ancient Vatican manuscript, with its crinkled brown pages and mottled writing. However, disappointed that I could not make out any of the words, I was about to close the window, when i had an idea! Using the XV software (also obtained from the net), I zoomed into a word and smoothed it into something legible. I had stumbled into a combination of resources that allowed me to examine the document.

And I didn't stop there. My school system's current agenda involves the reforming of the traditional daily schedule: we may initiate "block" schedules in the coming year. As student body president, I represent the school on the Superintendent's Advisory Board -- our mission: to investigate the pros and cons of block scheduling. We decided that most important, we needed to hear from students in other schools that had implemented the program. The nearest one was five hours away. A group of teachers had been bused in the previous month to visit for an hour or two of questions -- the only time available after travel time. No student on the advisory board wanted to repeat this exercise and in fact, we were almost reduced to drawing straws for a victim, when I had a sudden flash. A bit of background: The state of North Carolina has, within the past five years, set up a fiberoptics network that enables a teacher at one school to simultaneously each her home class as well as classes that are located across the county and even the state. My moher was teaching an oceanography class over the system and I knew that at least one of those schools was block-scheduled. At the next advisory board meeting, I moved that we postpone our road trip and use the fiberoptics network for an afterschool teleconference. Within four weeks, we had teleconferenced with two block-scheduled schools. We asked questions that mattered to students: what happens when you miss school; how are athletics affected; and, how are advanced placement classes organized. Moreover, the two block-scheduled schools were able to discuss their own variations of block scheduling

Computer technology has not simply affected my education; it has changed my personality. I have travelled from having a daydream about why spider webs are so strong, to performing concrete scientific research, to making an obscure document understandable (one that I did not know existed, but for the Internet), and I initiated a solution to a real-life organizational problem. I'm feeling pretty good

Frank "Gib" Gibson, 1994 national high school winner of the NSF NASA ED telecommunications essay, with teacher, Abigail Saxon

ronmental monitoring and waste management industries. Beginning in FY 1995, digital libraries of the large volume and wide range of environmental and waste information will be assembled and tools will be developed to make these libraries useful. These include:

- DOE site survey and regulatory information and tools to use these libraries (the DOE's existing weapons complex will serve as a natural testbed)

- A coordinated effort by NASA, NOAA, and EPA will jointly provide public access to a wide variety of Earth science databases, including satellite images, Earth science measurements, and in situ and satellite data from NOAA's environmental data centers.

- A joint NASA/NOAA/EPA effort will develop training and education to satisfy the public's environmental information needs.

- A National Environmental Information Index, as directed by the National Performance Review

- A NOAA Earth Watch pilot information system will provide integrated access to environmental information together with relevant economic and statistical data for policy makers and others.

Health Care

Advanced HPCC communication and information technologies promise to improve the quality, effectiveness and efficiency of today's health care system. This National Challenge will complement the biomedical Grand Challenges. It will include testbed networks and collaborative applications to link remote and urban patients and providers to the information they need, database technologies to collect and share patient health records in secure, privacy-assured environments, advanced biomedical devices and sensors, and system architectures to build and maintain the complex health information infrastructure.

Using a Broad Agency Announcement, NIH began funding the following activities in FY 1993, and is expanding efforts beginning in FY 1994:

- Testbed networks to link hospitals, clinics, doctor's offices, medical schools, medical libraries, and universities to enable health care providers and researchers to share medical data and imagery

- Software and visualization technology to visualize the human anatomy and analyze images from X-rays, CAT scans, PET scans, and other diagnostic tools

- Virtual reality technology to simulate operations and other medical procedures

- Collaborative technology to allow several health care providers in remote locations to provide real-time treatment to patients

- Database technology to provide health care providers with access to relevant medical information and literature

- Database technology to store, access, and transmit patients' medical records while protecting the accuracy and privacy of those records

A three-year contract was awarded in FY 1993 to a consortium of nine West Virginia institutions to use advanced networking technologies to deliver health services in both rural and urban areas. Other proposals received in response to the announcement will be funded in FY 1994.

Beginning in FY 1995, NIH will provide cancer prevention and treatment information to the public via several multimedia systems including Mosaic (described on pages 33-34).

An ARPA Biomedical Program will develop advanced biomedical devices and tools to build next-generation health care information systems.

NSF will expand a program in health care delivery systems begun in FY 1994. Included are activities in cost-effective telemedicine systems for distance medicine applications.

Manufacturing Processes and Products

Advancing manufacturing through the use of HPCC technologies in design, processing, and production of manufactured products is another National Challenge. A key element is the development of the infrastructure technology and standards necessary to make the processes and product information accessible to both enterprises and customers. This Challenge relies on network security and on the Digital Libraries and Electronic Commerce National Challenges, and is closely related to the Energy Management Challenge. On-going multi-year projects include:

- ARPA's MADE (Manufacturing Automation and Design Engineering) in America Program to develop engineering tools and information integration capabilities to support future engineering and manufacturing processes. These include the Center for Advanced Technology, a joint industry-government facility that offers world class manufacturing technology training; centers and networks for agile manufacturing; and a virtual library for engineering.

- Beginning in FY 1995, expanded NASA/industry/academia efforts in the multidisciplinary design of aeronautical airframes and aircraft engines will develop an integrated product/process development capability. This is intended to shorten the product development cycle, maximize capability, lower the life cycle cost, and obtain new insight into and understanding of the advanced manufacturing process, all critical to more competitive airframe and propulsion industries.

- NIST's System Integration for Manufacturing Applications Program emphasizes technologies that support flexible and rapid access to information for manufacturing applications. It includes a standards-based data exchange effort for computer integrated manufacturing that focuses on improving data exchange among design, planning, and production activities. Results will be made available to U.S. industry through workshops, training materials, electronic data repositories, and pre-commercial prototype systems.

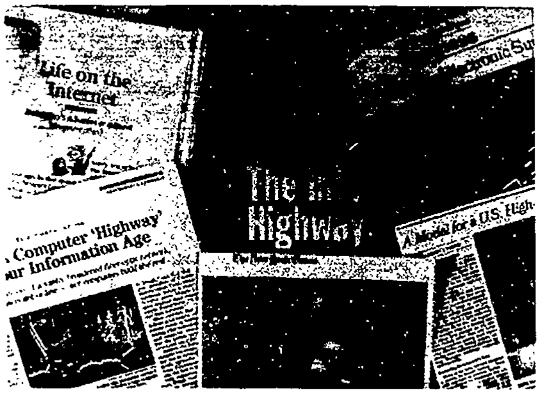
- At NIST, an Advanced Manufacturing System and Network Testbed supports R&D in high performance manufacturing systems and testing in a manufacturing environment. The testbed will be extended to include manufacturing applications in mechanical, electronics, construction, and chemical industries; electronic commerce applications for mechanical and electronic products; and an integrated Standard Reference Data system. The testbed will serve as a demonstration site for use by industrial technology suppliers and users, and to assist industry in the development and implementation of voluntary standards.

- NSF will support research leading to the development of information infrastructure technologies that support manufacturing design. Initial focus will be on virtual and rapid prototyping.

Public Access to Government Information

This National Challenge will vastly improve public access to information generated by Federal, state, and local governments through the application of HPCC technology. On-going efforts include connecting agency depository libraries and other sources of government information to the Internet to enable public access; and demonstrating, testing, and evaluating technologies to increase such access and effective use of the information.

For example, the White House, the U.S. Congress, and the HPCC Program make information available on the Internet. Other examples are ARPA's research in delivering computer science reports and literature to researchers



The concept of the NII's "Information Superhighway" has captured the imagination of the Nation.

and the public; NSF's Science and Technology Information Service and its support for the Securities and Exchange Commission's Edgar system; NSF's pilot project to demonstrate the use of the Internet and Mosaic in disseminating NSF information about program activities and accomplishments; DOE efforts to make energy statistics available to the public; NASA/NOAA/EPA efforts to make environmental data available to researchers and the general public; and Public Health Service (PHS) sponsorship of a variety of electronic information services, including NIH and NLM Internet servers that also provide connectivity to other health information services such as the bulletin board at the Food and Drug Administration and the PHS AIDS bulletin board.

7. Basic Research

Basic research projects focus on developing new methods to address fundamental limitations in HPCC technology as the Program proceeds and ensuring that the foundations for the next generation of HPCC technology are developed. Much of the advanced basic research is carried out in the academic community in cooperation with industry.

- ARPA funds basic research coupled to its other efforts in high performance computing. Basic research areas include design science, human/computer interaction, human language technology, persistent object bases, and software foundations. In addition, ARPA funds a high performance computing graduate fellowship program to focus attention on the critical need for people trained in this field.

- NSF funds long-term investigator-initiated research and continues to encourage interdisciplinary research, collaboration between computer scientists and applications scientists in solving Grand and National Challenges, and cross-sector partnerships. It funded 350 investigator-initiated projects and awarded 77 postdoctoral research and training grants (one grantee was a 1993 Supercomputing Forefront Award Winner). NSF-supported researchers contribute to fundamental networking, memory, interconnectivity, storage, and compiler technology, and the agency plans to support research in virtual reality. NSF, ARPA, and NASA jointly funded High Performance Fortran development.

- In FY 1995 NSF plans to support 100 new investigator-initiated projects in new areas, support 30 new postdoctoral fellows, and initiate three new programs — graduate fellowship (20 awards initially), Industry/High Performance Computing Centers visitor program (16), and Software Infrastructure Capitalization (2).

- NSF also supports the procurement of scalable parallel systems for basic research and in FY 1995 will support infrastructure for National Challenges.

- DOE funds basic research at agency laboratories and at 30 universities including over 40 postdoctoral associates and over 60 graduate students. Subjects include numerical analysis and scientific computing, modeling and analysis of physical systems, dynamical systems theory and chaos, geometric and symbolic computation, and optimization theory and mathematical programming.

- NASA sustains research efforts in architec-

tures, algorithms, networked distributed computing, numerical analysis, and in applications-specific algorithms. It has research institutes and centers of excellence at the Illinois Computer Laboratory for Aerospace Systems and Software, and at its Ames, Langley, and Goddard centers. It is expanding support for postdoctoral research, new professors, and its Graduate Student Researchers Program at NASA centers.

- NIH has formal degree-granting fellowships in medical informatics and cross-disciplinary training of established investigators. The agency sponsored hands-on training of biomedical researchers in using computational biology tools at NSF Supercomputer Centers.

- EPA supports cross training of computational and environmental scientists.

8. Training and Education

A natural consequence of basic research in HPCC technology is education and career development. Each generation of HPCC researchers trains and educates the next generation. The workforce becomes increasingly technologically sophisticated, providing myriad economic and social benefits to the Nation.

- NSF Supercomputer Centers conduct some 200 training events for 3,000 trainees each year. The agency provided about 20 computer systems to colleges and universities, including minority institutions, and funded five SuperQuest teams each with four students and two teachers investigating their own scientific projects; over the years 64 such projects have been funded. In FY 1995 the agency will provide 13 more entry-level systems to universities and expand SuperQuest.

- NSF provides on-going support for training and education programs for teachers and students at all levels. In their program supporting VLSI (very large scale integration) fabrication by Mosis (metal oxide semiconductor implementation service), NSF and ARPA fund 1,200 student projects per year; over six years 30,000 students from 170 universities in 48 states and the District of Columbia have been funded. The agency supports pilot projects demonstrating the application of advanced technologies in education. Included are the "Common Knowledge" project involving the Pittsburgh school district, the "National School Network" involving teachers and students at all pre-college levels, and the "Learning through Collaborative Visualization" testbed.

Father and daughter using the KidPix graphics program on a Macintosh during "SDSC Kids' Day" at the San Diego Supercomputer Center.

- DOE educational programs include Adventures in Supercomputing for in-service teacher training (50 teachers and 25 school districts in five states in FY 1995). Superkids for high school student summer enrichment, and undergraduate and graduate electronic textbook projects.

- NASA supports undergraduate and graduate level training. New NASA mechanisms will support students and new faculty interested in applying HPCC technology, especially by directly funding students with advisers interested in NASA applications.

- NASA will continue its K-12 Educational Outreach Program at seven NASA field cen-

ters nationwide to develop curriculum products and teaching aids in computational science and networking for education. Teachers located near the field centers will participate in each project. Finished products will be available to all teachers and students via the Internet.

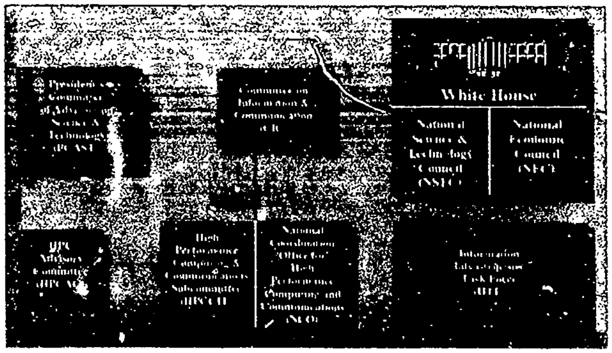
- ARPA has a unique program supporting historically black colleges and universities; strongly encourages affiliation with local communities; and is accelerating technology transition through community-wide efforts such as the National Consortium for High Performance Computing.

- NIH will support development of interactive learning tools for improved science education. The agency has a pilot project to educate high school science teachers and students about computational techniques for biomedical science.

- NOAA provides its agency staff with education and training in the use of scalable systems.

- EPA is developing a prototype training program that includes a series of pilot projects with Federal, state, and industrial environmental groups. The agency funds fellowships and graduate student support in environmental modeling, supports undergraduate students, and supports environmental learning experiences for junior and senior high school students. It will develop environmental education tools for grades 9 through 12.

Through these efforts, more students will choose careers in HPCC technology and its application, resulting in more widespread and advanced knowledge of these fields. The long term benefits of these education programs will include increased awareness and education of the general public about high performance computing and communications and the application of HPCC technology to improve the quality of life in the U.S.



9. HPCC Program Management

The HPCC Program reports to the Director of the Office of Science and Technology Policy. At his direction, overall Program budget oversight is provided by the National Science and Technology Council through its Committee on Information and Communication. In September 1993, the National Coordination Office for High Performance Computing and Communications (NCO) completed its first year of coordinating the HPCC Program and serving as a liaison to the U.S. Congress, state and local governments, foreign governments, industry, universities, and the public.

The High Performance Computing, Communications, and Information Technology (HPCCIT) Subcommittee and its Executive Committee coordinate Program planning, budgeting, implementation, and review; meet with other Federal organizations with mutual interests; and communicate with other Federal agencies and the U.S. Congress. In FY 1994, the Subcommittee met with technology experts from leading hardware, telecommunications, and software companies. The representatives were asked to comment on the Program and provide advice on technical and programmatic issues in high performance computing and communications. Similar meetings are planned with other constituencies.

HPCCIT working groups coordinate the efforts in the various Program components. The newest

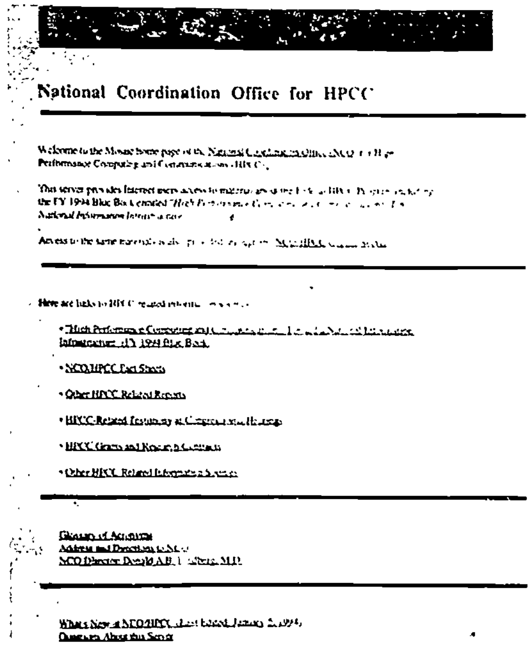
one, the Information Infrastructure Technology and Applications Task Group, established in 1993, has developed coordinated agency plans for R&D in NII technology and National Challenge applications. The networking working group coordinates its activities with the Federal Networking Council (FNC) whose membership extends beyond HPCC. The FNC establishes strategy and policy direction, provides further coordination, and addresses technical, operational, and management issues of the Interagency Internet. Its Federal Networking Council Advisory Committee represents a broad spectrum of network users and providers. Both individual agencies and these working groups sponsor meetings with industry and academia, including biennial meetings with hardware vendors to discuss plans, and periodic Grand Challenge workshops.

The early success of the HPCC Program is now providing it with one of its greatest management challenges, as more programs use its technologies, as new sectors of the economy are relying on scalable parallel systems, and as more people are becoming aware of its value to the Nation. The Program itself is highly leveraged across many other governmental and private sector programs, and the synergy between the emerging technologies and pilot applications of this R&D program is revealed in numerous other application areas. Practically every Federal agency has activities that are not part of the HPCC Program but that use the technologies and results from the Program. Some of those associated with agencies that participate in the Program are described in this document. Other education, health care, design for manufacturing, and related scientific research programs are not part of the HPCC Program but depend on HPCC technologies. The explosive growth of computing and networking will result in the pervasiveness of high performance computing and communications that are the foundation of the NII.

10. Information about the HPCC Program

In FY 1993, the NCO held some 50 meetings with representatives from the Federal and other governments, industry, and academia. The HPCC Program actively seeks input and advice from all interested parties.

The NCO has provided electronic, print, and video materials to hundreds of media representatives in the U.S. and abroad, and responded to thousands of information requests from Congressional offices, industry, academia, and the public. The NCO distributed over 20,000 copies of its FY 1994 Annual Report entitled "High Performance Computing and Communications: Toward a National Information Infrastructure." That 186-page book details Program goals, activities, accomplishments, and plans, and complements this shorter document. Some 300 copies of the six-



"Home Page" for the Mosaic interface to the HPCC WWW (World-Wide Web) server. Established in October 1993, this server was accessed by 900 users in February 1994. Its URL (uniform resource locator) is: http://www.hpcc.gov/

Mosaic was developed at the National Center for Supercomputer Applications (NCSA), an NSF Supercomputer Center. Mosaic may be the first "killer ap," that is, an extremely successful application in the National Information Infrastructure. Thousands of servers around the world can be accessed using Mosaic, which is available for Unix, DOS Windows, and Macintoshes.

minute video of the same name have been distributed. The video has been used in a number of television reports.

In FY 1994, the NCO established World Wide Web and Gopher servers as well as anonymous FTP (file transfer protocol) capabilities for electronic dissemination of information about the HPCC Program over the Internet. The servers allow users to view and download information about the HPCC Program including the FY 1994 Annual Report, this FY 1995 Annual Report, information about sources of funding for HPCC R&D, and related materials. These servers also provide links to other servers, including those managed by HPCC agencies and the Information Infrastructure Task Force. At Supercomputing '93, held in November in Portland, OR, the NCO demonstrated these technologies and distributed materials to thousands of visitors.

High Performance Living Today and Tomorrow

High performance computing and communications have already had a profound impact on the lives of all Americans. Among the benefits: better prediction of natural disasters such as hurricanes; more rapid deployment of needed services in times of crisis; the use of more and more powerful computers to solve complex problems never dreamed of a decade ago.

In the past year, the concept of the "Information Superhighway" has captured the imagination of persons from all walks of life and around the country. Millions of Americans have discovered its precursor, the Internet. Millions more have read about it. Even more are vaguely aware that computers can somehow help them obtain information rapidly and communicate instantaneously with others around the world.

Americans are also discovering that computing and communications help to save lives, direct scarce resources, and locate survivors. When an earthquake struck Southern California this winter, a record number of persons logged onto commercial and nonprofit networks to learn about the safety of loved ones.

A typical example is that of a 62-year-old woman in Arizona who was concerned that she could not reach her son in the Los Angeles area following the quake. She called her brother near Indianapolis who called his son in Dallas, who in turn used his home computer to inquire about the whereabouts of his cousin. Several hours later, a total stranger in California called the mother to report that her son was unhurt.

A record cold spell and snowfall paralyzed much of the East Coast this winter. Tens of thousands of businesses were closed. What happened? Hundreds of thousands of workers stayed home, but many of these continued working. As snow and ice blanketed the East Coast, they communicated electronically and telecommuted while avoiding the icy roads. Similarly in California after the quake, where demolished freeways and unstable buildings made a normal business routine nearly impossible, a record number of workers and businesses turned to telecommuting as the region began to rebuild.

Imagine the possibilities with a ubiquitous information infrastructure, one accessible by all Americans, which allows users to use two-way video as easily as they use the telephone or fax today.

The Federal government and the HPCC Program firmly believe that the NII should and will be built primarily by the private sector. One role of government in this monumental undertaking will be to conduct government information intensive activities in ways that support the testing, development, and deployment of new technologies to meet the nation's networking and computing needs in the coming century.

The following scenarios illustrate how high performance computing and communications and the NII can benefit all Americans in the coming years. Many of these activities are already or will soon be taking place in research and educational settings. Much of the future described is already here, but only for a relatively small number of users. The challenge faced by the government is to ensure that these benefits are accessible by all Americans from all walks of life. And that we spur the development of the best possible technologies for a truly National Information Infrastructure to be shared equally by all our citizens.

CRISIS MANAGEMENT: EARTHQUAKE RELIEF IN THE YEAR 2000

A series of minor tremors along a major California fault line over the past two months has fueled more than premonitions that "the big one" might soon come. Real-time assessments of the probability and potential location of a severe earthquake have been continuously relayed to state and local emergency managers via the National Information Infrastructure. In turn, these managers use their real-time logistics and management control system to determine the state of readiness in each community within the region.

These last minute preparations are just in time. Within seconds of the massive earthquake, real-time computer analysis of seismic monitoring data from a broad array of sensors placed across the region and nation pinpoint the location and magnitude of the quake. Before the initial jolt is over, an automated regional resources management system combines the new data with a large data base that describes in detail the geological structure of the area. A map appears showing the areas most likely affected, and the kind and degree of earth motion expected in each area.

This geographically referenced information is consistent with a standard geographic encoding of the area, which enables other emergency response systems to spring immediately into action.

Within the first 30 seconds of the onset of "the big one," this information is fed into still another interconnected computer system that contains a detailed data base of buildings, highways, and other structures in the affected area. The system shows the expected ability of these structures to hold up after the kind of earth motion just experienced and that to be expected as a result of aftershocks from a quake of this magnitude.

Another database predicts the expected distribution of people in those areas, taking into account the time of day, special events that are underway, and real-time data for hotel and theater occupancy rates, traffic distribution, and the location of hazardous materials in every building, truck, and train throughout the area.

Still within a minute of the initial jolt, a master database combines all this and other data, such as the prevailing and forecasted weather conditions, to create an instant picture of the likely nature and extent of this major emergency.

Alarms are quickly activated in emergency control centers, fire and police stations, hospitals and other medical care centers, and in the offices and homes of local, state, and federal emergency officials. By the end of this first minute, "informed" emergency bulletins immediately interrupt the routine in all schools, offices and homes in the area, providing a concise message of what has happened and what to do.

As a result, emergency resource teams are deployed within a few minutes of the quake, knowing where they are most needed and what types of injuries to expect. Hazardous materials response teams are dispatched to the needed sites, armed with current information about the location and nature of the hazardous materials and the latest weather data. Appropriate warnings are issued, allowing the general public to take immediate action to protect their safety.

In the hours following the quake, this information is updated continuously and is relayed to emergency support teams, hospitals, government officials, and private sector managers. Wireless interfaces and satellite links ensure the rapid transmission of critical information to teams working in areas where phone and electrical lines are disrupted. Community centers and others register millions of local residents for quick location by loved ones and a first step in emergency assistance programs.

The result? Thousands of lives saved through fast, appropriate emergency response, and billions of dollars of property protected from unnecessary danger, such as hazardous materials or other threats.

EDUCATION AND LIFELONG LEARNING

Advanced computing and communications technologies have revolutionized the way many students learn. Elementary school students correspond with electronic pen pals around the world, learning more about faraway lands, cultures and current events than from mere lectures; students from three geographically distant high schools collaborate to simultaneously measure the distance from the earth to the sun, learning invaluable lessons in math, science, and communications; other students visit distant art museums and other educational sites via "electronic field trips." Interactive multimedia encyclopedias and other learning tools allow students to select a myriad of information — sound, video, maps, charts, and text — on virtually any subject.

Because of high performance computing and communications, academic research will continue to change at an increasingly rapid pace. The many collaborations of scientists in the 1990s, such as remotely sharing scientific instruments and simultaneously working on scientific problems from distant sites, will, within a few years, likely result in even more and increasingly sophisticated collaborations involving geographically diverse researchers and institutions.

For example, a National Virtual Laboratory will allow geographically distributed researchers to share experimental results, collaborate on team research projects, and share coursework for their students who are also geographically distributed. Likely collaborations will include projects that are too expensive for one institution to perform, such as research on robotic vehicles.

Simulation-based education and training will increasingly be used for on-the-job training. For example, the aircraft industry has long used flight simulators for pilot training, especially in handling emergency situations. Today, simulation is also being used in training across the field — while aircraft are still under construction, mechanics are learning maintenance and repair via computer simulation. By the time the planes are built, these mechanics will be able to confidently and efficiently maintain and repair the craft within weeks rather than the year it used to take.

Education and the NII circa 2000

Fifteen blocks from Yankee Stadium in the South Bronx, it is the elective period for several sixth grade students in P.S. 91. They are sitting in front of computers and are wearing headphones with attached microphones.

Renaldo is studying Chinese with two dozen other students scattered around the city led by a teacher in Queens. On the screen two children say, in Chinese, "It's nine o'clock." The teacher asks Renaldo to repeat the phrase. "Very good, Renaldo," she says.

At the next desk, Laverne is working on a solid waste project with Cindy, her "key pal" in Schoharie County in upstate New York. Laverne and Cindy met when Laverne posted a question on a bulletin board about recycling. Cindy lives on a farm and organized a plastic recycling program when the local dump was in danger of exceeding its capacity.

Eric is in the music section of the library assembling material for his research "paper" about Duke Ellington. He attaches pieces of a 1942 audio recording and the 1959 video clip of "A Train" to illustrate the changes in orchestration styles between those times.

Mrs. Esformes, the classroom teacher, is "attending" a seminar on teaching visually impaired children. She has a blind student this term and she is comparing her experiences and techniques with 14 other teachers from around the city who are also working with severely visually impaired students for the first time. The leader of the seminar is a professor in Madison, WI.

Lifelong Learning

The NII will also aid in lifelong learning, making it more accessible to millions of Americans. Jennifer, a secretary at a small marketing firm,

wants to complete her college education and receive a degree in geology. Although the small business for which she works has no formal educational assistance program, they offer to let her use their computers and network connection on her off hours. During her lunch break, for example, Jennifer is enrolled in an interactive class on soil conservation. She is able not only to listen to and see the lecture, but can ask questions via a microphone at her workstation. If other classes, however, are not offered at a time she can attend, the computer can store the transmission of the class for later viewing. Questions can be mailed electronically to the professor, who can send answers back the next day. And when it is time to write a term paper on the effects of heavy rains in the Rocky Mountains, Jennifer can electronically access databases and academic and specialized libraries around the world. She retrieves, electronically, a topographical map of the Western Slope of the Rocky Mountains. Using a mouse, she moves an icon to a certain point on the ridge, and releases a drop of water to see which way it flows downhill Using existing databases, she is able to create a scenario for the soil effects of heavy rain in the area, including the projected loss of specific minerals in the land.

ELECTRONIC COMMERCE

Electronic Banking

Imagine 20 years ago, being told that you could go to a city virtually anywhere in the world and receive instant cash with a wallet sized card. Not so many years ago, emergency cash on a weekend was something obtained from friends or relatives with ready money or through the graces of a check-cashing card at the local grocery store. Today, automated teller machines can provide cash across the country and around the world.

Automated teller machines have revolutionized the way we bank. Americans no longer try to fit their hours around the narrow "bankers' hours" of yesteryear. And banking institutions have actually expanded their operations in response -- offering satellite banks in grocery stores, and evening and even Saturday hours. Commercial electronic shopping networks already exist; tax returns can be filed electronically. Why not online applications for loans or other financial needs that can be completed at home at one's leisure?

These are but a few examples of the many benefits electronic commerce can bring to American society. But, unless developed carefully and wisely, these benefits could carry enormous risks. To date, electronic commerce has taken place in protected networks maintained by banks or other businesses. Ensuring privacy, security, and authenticity is essential for a National Information Infrastructure.

Today's Internet is a fabulous example of what a little federal investment can stimulate. But it was designed as, and remains, a tool for research and education, an opportunity to explore what is possible and what works best. HPCC-funded gigabit testbed sites explore not only higher speed transmission of data, but how such data can best be used and shared in the real world, and how best to protect the privacy of its users. Applications such as electronic banking can benefit from these efforts.

Electronic Brokering

Electronic brokering services are already demonstrating significant savings in time and money. The ARPA-funded Fast Brokering system for small purchases, for example, has proven in several pilot studies that it can operate five times faster than standard procurement procedures. When an item is needed, a data base search considers not only the lowest price, but the projected delivery date, and past performance by the suppliers, to determine the most suitable provider or providers for the item. Potential vendors are then notified electronically, or via fax or phone, and asked for price quotes and delivery dates. Currently in pilot use at some 20 military bases across the country, the system has reduced the number of days from the request for quotations to completed procurement from 96 to 20 days.

Under this system, intragovernment lines of funding are established with the broker, who then transfers the funds to the supplier upon acceptance of the delivery. New payment mechanisms, such as credit card or debit payments, will need to be integrated into the system to support the more spontaneous transactions demanded by consumers.

Consumers could receive price quotes on specific products as well as related reports on performance and customer satisfaction, and information on suppliers (such as store hours, delivery terms, warranties, length of time in business, and reports from consumer protection agencies such as the Better Business Bureau).

Electronic commerce will enable consumers to make more educated choices about their purchases, ana at the same time, enable businesses and manufacturers to provide the kinds of information and products most needed by Americans.

BUYING A CAR IN THE YEAR 2000

Jim and Rhonda grudgingly agree it is time to buy a new car. They have held on to their old vehicle in part because of how much they hated their last car buying experience — the hours spent at the library evaluating specific cars; the seemingly endless trips to car dealers where they were provided with little information other than glossy brochures; the hassles of getting a loan and new insurance; and the disappointment upon later learning that one of their neighbors bought the same car for much less.

This time, they think, maybe their computer can help. They know they need a larger vehicle for their growing family, but which is best — a minivan or station wagon? A quick literature search pulls up independent reviews that outline the advantages and disadvantages of each model.

Still not sure which they would prefer, Jim and Rhonda review safety and performance reports on two minivans and two station wagons chosen from their initial search. The computer provides independently produced reports on consumer satisfaction, as well as the estimated maintenance and operating costs of each model.

The couple now decides to take a look at the candidate cars — the automobile manufacturer's computer server allows them to see a video of the car, as well as make selections to view different colors, interiors, upholstery, and other options. The interactive display allows them to select options such as engine size, sound system, rear passenger air bags, and customized climate controls, while at the same time showing the estimated cost for these options and the impact on fuel consumption. This computer service actually allows the couple to custom design their car, choosing power brakes, for example, while bypassing power windows if they prefer. The availability of a car with the chosen options is shown at the bottom of the screen, along with an estimated delivery time for special orders. Reviewing the various packages available, the couple narrows their choice to two models.

While Jim and Rhonda could order their car directly from the manufacturer, like most drivers they want to experience for themselves how the car feels and handles, and find a reputable dealer near their home who can perform routine maintenance and handle repairs.

Using electronic "yellow pages," they request information on dealers carrying the two cars located within a 10-mile radius of their home, who also have service hours on Saturdays and until at least 8 p.m. on weeknights, and offer shuttle service to and from public transportation or work. These are displayed on a computer-generated map. Using the computer mouse to click on a specific dealer, information is displayed on the length of time the dealer has been in business, and other considerations, such as whether loaner cars are offered, and customer satisfaction rates.

Jim and Rhonda electronically notify two dealerships that they would like to make appointments for test drives on Saturday morning.

Using an electronic brokering service, the couple now checks information on the best advertised price for the cars, and whether it is best to

lease or buy. The service also checks for the best loan terms available for a new car purchase, and offers electronic loan application forms that can be filled out, then electronically sent to the chosen lender. Another click and the couple compares insurance rates for the two cars — is one more likely to be stolen and therefore more expensive to insure? How much can they save on insurance rates by investing in an alarm system? What company offers the best rates for their particular driving history and needs? Which has the greatest level of customer satisfaction in processing claims?

On Saturday morning, the couple test drives the two cars. That afternoon, they issue an electronic bid, which is answered by an electronic commerce service. They then pick the best offer and, upon acceptance, activate a process that orders their new car from the factory. Electronically generated loan and insurance procedures are carried out as well, so that a week later, when the dealer's shuttle comes to pick them up at their home, the couple signs the papers and drives home in their new car. "That wasn't so bad now, was it?" asks Jim. "No," responds Rhonda. "I can't imagine why I dreaded it so much. It was really quite fun."

Much of the technology described in this example of electronic commerce is available today, but on a far more limited basis. These innovative services will primarily be developed by private industry and public consumer organizations. The Federal government's role in these efforts will be to help develop the most effective technologies, ensure standards for interoperability of different multimedia systems, and spur the development of security measures to ensure privacy and protect against consumer fraud.

Advanced security protections such as encryption technology and authentication measures are crucial to the widespread use of electronic commerce, and the ability for Americans to conduct their business over the NII.

Services to support the publication, dissemination, and access of multimedia information will make electronic commerce readily available to the American public as well. Intelligent services will make it easy and convenient for first-time users to easily browse information spaces with a combination of speech and graphics and to delegate tasks associated with brokering to automated agents.

These services extend far beyond consumer convenience — when Jim and Rhonda access the car manufacturer's computer, for example, it tracks the combination of features and options most sought by browsers, alerting the manufacturer to those that consumers are most and least interested in. A special option that is viewed frequently, but then rejected because of the price, could be popular enough to make in larger quantities for a lower price. These data, as well as those on what customers actually buy, can help auto manufacturers respond quickly to customer needs, and at the same time, increase their competitiveness in the global economy.

INCREASED PRODUCTIVITY THROUGH IMPROVED ENVIRONMENTAL DATA

The use of the latest information technology, coupled with more timely and complete environmental information provided by the government, is essential for U.S. industry to succeed in the highly competitive global marketplace.

American industry already makes substantial use of real-time and historical weather and other environmental information from NOAA to optimally route airplanes, trucks, and ships, thereby minimizing transit time and fuel consumption and assuring safer travel.

More timely access to more comprehensive environmental information will support both day-to-day and long-term business decisions by thousands of large and small companies. Marketing and distribution decisions, key ingredients in economic growth, are driven by readily available information. Companies are already using high performance computing technology pioneered by the HPCC Program to sort through extremely large volumes of data, seeking patterns for potential sales of products and services that will both minimize resource consumption and maximize bottom lines. Increased availabil-

ity of the Nation's vast amounts of environmental data on the NII will allow companies to improve the ways their inventory and distribution operations respond to changing weather conditions across the nation. This increases productivity and serves customers better. Weather sensitive indicators can be better factored into product development and marketing activities to achieve additional increases in productivity.

ENVIRONMENTAL MONITORING IN THE YEAR 2000

Michele, a biological oceanographer and fishing industry analyst, sits at her workstation at the Western Regional Environmental Center analyzing predictions for a record pollock catch off Kodiak Island. The source? Observations from an on-going cruise in Alaska's Shelikof Strait that suggest the recent El Nino-Southern Oscillation (ENSO) event is influencing the fish harvest in the area.

The analyst, whose job it is to guide the U.S. fishing fleet, has her doubts, however. She is accessing data from satellite-linked moored subsurface ocean sensors, polar-orbiting satellites, numerical forecasting models, and coastal sampling stations from the past three months. All these data indicate that warm tropical water has been progressively moving northward along the U.S. and Canadian Pacific coast. Real-time data from satellite-linked drifting buoys and current meter arrays, as well as ship surveys of fish egg and larvae, suggest a major circulation anomaly is occurring in the spawning region off the coast. In fact, what looked like a high catch year seems to be turning into an economic bust!

Observations from an on-going cruise in the area, as well as the beginning of disturbing reports from fishing boats also hint that something may be wrong.

Using a mouse, Michele clicks a satellite icon that downloads the most recent 24-hour set of visible and infrared imagery from NOAA and NASA ocean-observing satellites. After clicking another icon, a new window opens that allows her to extract and compile a time series of the last 30 days of infrared imagery from the NASA satellite database in Pasadena, CA, and the NOAA satellite database in Suitland, MD. Using tools available on the NII, she is able to quickly integrate these disparate data sets spread across the country and to create an animation that clearly shows the progression of warm tropical waters toward the Alaskan coastal region that serves as a safe nursery for pollock larvae.

In order to put this environmental event into perspective, Michele next queries the National Oceanographic Data Center ship observations data base in Washington, DC, for the past 50 years of sea surface temperature data. Using a graphical user interface available on the NII that lets scientists intuitively explore and visualize a variety of multi-dimensional data products, she zooms in on the North Pacific and quickly creates a 50-year animation loop of sea surface temperature. In another window of her workstation, she accesses the ENSO and Equatorial Undercurrent oceanographic database at the University of Washington. Next she creates a new graphical overlay of her data that suggests a long-term, phased relationship between equatorial processes and sea surface temperature in the northern Pacific. This visual observation is confirmed by running correlation and coherence analyses using a point-and-click time series package, available on the NII from the Scripps Institution of Oceanography in La Jolla, CA.

Based on these data, she is able to project nearby regions where the fish are likely to go. With another icon selection, she overlays several tracks of drifting buoy data and subsurface moored current meter data onto the satellite imagery. These data suggest that the planned track of an observation cruise underway will have to be modified to properly sample the new circulation feature and the whereabouts of the fish. To plan for the new cruise track, she checks the online National Weather Service's five-day weather forecast and the Navy's Pacific Ocean Circulation Model forecast for the study region.

The ship's captain is fully informed through the ship's onboard workstation, which is networked

by satellite link to the shore-based support systems, of the relevant observational and environmental forecast information. He instantly accesses electronic maps and charts to plan a changed course. Several hours later comes the news — yes, the fish have moved. Michele notifies the Northwest Pacific Fishery Council, which in turn issues a recommendation to relocate the commercial fishing activities.

DELIVERING HEALTH CARE TO REMOTE AREAS

Lisa knew something was seriously wrong when the pain awakened her from sleep. She was no stranger to adversity, having lived her life in the Appalachian highlands where getting help with any sort of problem meant a long drive over winding mountain roads. But being a first-time mother-to-be brought special challenges, and this throbbing headache — the worst she'd ever experienced — made her sense of isolation as dark and deep as the night's sky over the Blue Ridge peaks. She picked up the phone and called the emergency number at the Valley Health Clinic. The nurse practitioner who answered the phone told her what she already knew: Dr. Clark, one of a few circuit-riding obstetricians who covered this sparsely populated part of the state, would be holding the coming day's clinic hundreds of miles away. But the nurse added, "We'll be able to get his help as if he were right here," and directed Lisa's husband, Mike, to get her to the clinic promptly.

The couple arrived at the little clinic just as first light was outlining the nearby ridges. Lisa was worse, her vision becoming occasionally blurred. She knew the baby wasn't due for another four weeks, and she was scared that these symptoms might mean the baby was dying. The comforting words of the nurse, and her careful exam, helped to lessen the fear, but the findings were not good: Lisa's blood pressure was elevated and the fetal heart sounds were weak. The nurse said it might be a disease called "toxemia of pregnancy" and that she might need to go to the hospital. "Hospital! But that's a four-hour drive over the mountains, and if she could get better just by resting, we sure don't want to put her through that," Mike replied.

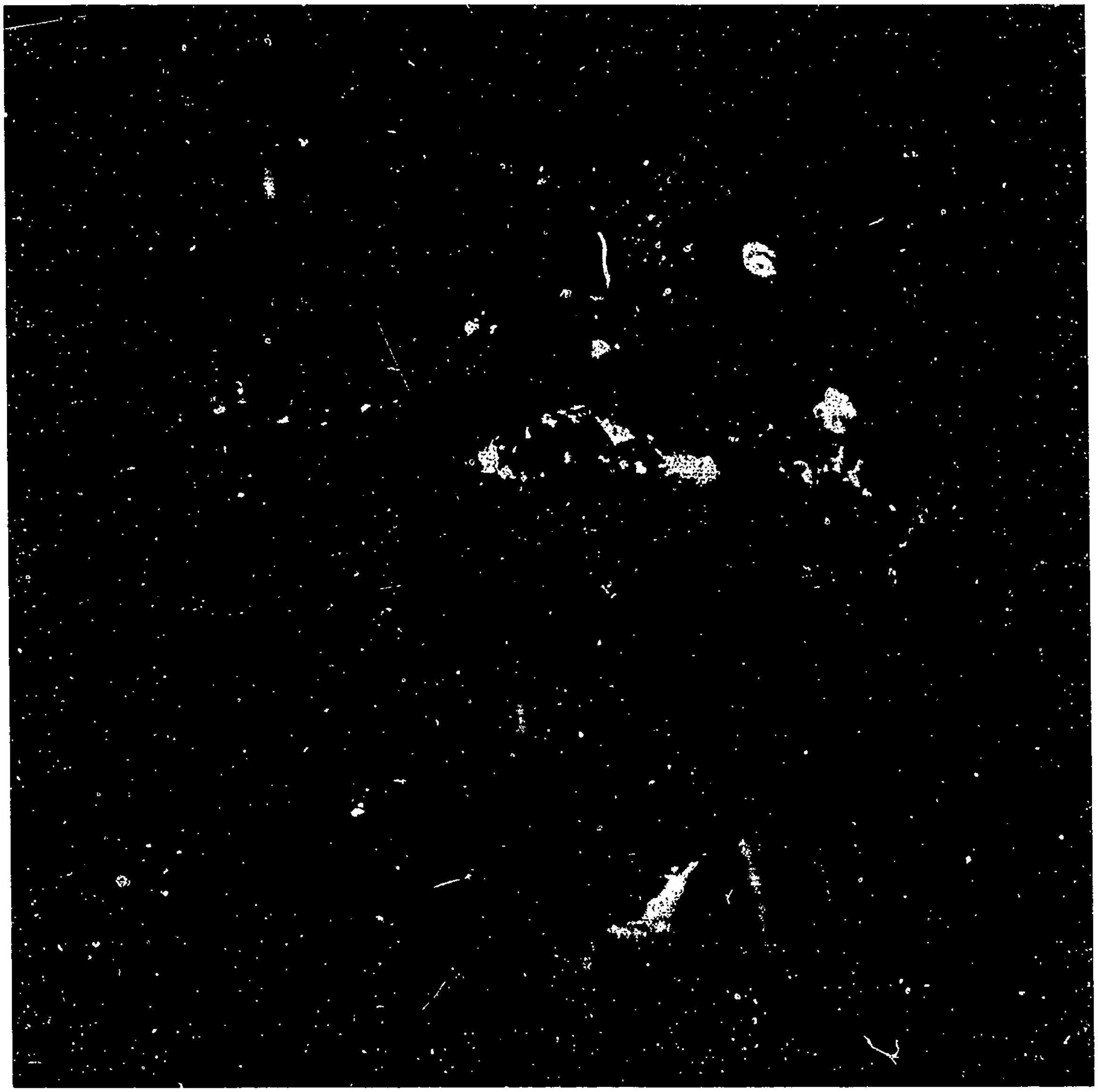
A few years before, the nurse and the family would have had to call Dr. Clark on the phone and get his opinion, an educated guess really, about whether to undertake the arduous journey. But high performance computing and communications had changed that. For the telemedicine workstation in this little two-room clinic now brought medical expertise from far away right to Lisa's side. Initiating a two-way video link, the nurse brought Lisa "face-to face" with the doctor, who had been reviewing the previous day's X-rays at his own office workstation several hundred miles away. He greeted Lisa and observed from her expression that she was in much pain. He asked a few questions about the headache and vision problems, then asked the nurse to put the fetal ultrasound transducer on Lisa's abdomen. The image of the baby in the womb simultaneously appeared on the clinic workstation screen and on the distant physician's workstation. Dr. Clark guided the nurse to turn the sound beam right and left to obtain a better view as nurse, doctor, and patient watched the screen. The fetal electrocardiogram, a continuous tracing of the baby's heart, traced a regular pattern in another window on the workstation while Lisa's blood pressure was recorded and displayed digitally by an automatic blood pressure cuff.

"This certainly looks like toxemia," Dr. Clark said, "but something else is going on as well — the baby's heart rate is intermittently slowing for some reason. Try moving the ultrasound probe over here." Using an on-screen marker, he pointed out the baby's head and neck, and the nurse tilted the pencil-like probe that rested lightly on Lisa's abdomen. "There it is!" the doctor exclaimed, as the outline revealed the umbilical cord wrapped several times around the baby's neck. As the child moved in the womb, the umbilical blood supply was occasionally pinched and the baby's heart rate slowed down, a sign of fetal distress.

Lisa would need a Cesarean section to preserve the baby's health. What might have been an educated guess and an unexplained abnormality

before high performance computing and communications was instead a certain diagnosis. And the hospital caring for her was well prepared for immediate action upon her arrival. The nurse used multimedia privacy-enhanced electronic mail to send the ultrasound images, electrocardiograms, and even Dr. Clark's video interaction with the patient to the receiving hospital staff. A simple point-and-click interaction on the workstation screen gathered the various signals and images. Together with copies of Lisa's prenatal care clinic notes, the nurse sent a comprehensive electronic patient record to the distant facility. When Lisa arrived later that day, the ward staff recognized her immediately and welcomed her as if she were an old friend.

The baby girl delivered by Cesarean section that afternoon started life a few weeks early, but grew and thrived. It would be many years before she could comprehend or even spell "National Information Infrastructure," but her mom would say, "We had to save your life when you were just a picture on the screen." The decisions made with speed and certainty that fateful morning depended on many information technologies: ubiquitous high speed digital communications techniques; medical computer workstations with advanced motion graphics and video; and secure methods to protect confidentiality and privacy of network communications. This young mother in rural Appalachia still doesn't know much about computers, but she knows she got speedy and effective health care. And she knows the bright eyes of a healthy child, brought safely into the world with the help of high performance computing and communications.



Monitoring Hurricane Andrew from geostationary orbit. This image from the NOAA GOES-7 spacecraft is an example of the type of data that are being made available on the Internet and are of great interest to the public as well as the meteorological community.

HPCC Program Summary

HPCC Program Goals

Extend U.S. technological leadership in high performance computing and computer communications.

Provide wide dissemination and application of the technologies to speed the pace of innovation and to improve the national economic competitiveness, national security, education, health care, and the global environment.

Provide key parts of the foundation for the National Information Infrastructure (NII) and demonstrate selected NII applications.

HPCC Agencies

ARPA – Advanced Research Projects Agency, Department of Defense

DOE – Department of Energy

ED – Department of Education

EPA – Environmental Protection Agency

NASA – National Aeronautics and Space Administration

NIH – National Institutes of Health, Department of Health and Human Services

NIST – National Institute of Standards and Technology, Department of Commerce

NOAA – National Oceanic and Atmospheric Administration, Department of Commerce

NSA – National Security Agency, Department of Defense

NSF – National Science Foundation

HPCC Program Strategies

Develop, through industrial collaboration, high performance computing systems using scalable parallel designs and technologies capable of sustaining at least one trillion operations per second (teraops) performance on large scientific and engineering problems such as Grand Challenges.

Support all HPCC components by helping to expand and upgrade the Internet.

Develop the networking technology required for deployment of nationwide gigabit speed networks through collaboration with industry.

Demonstrate the productiveness of wide area gigabit networking to support and enhance Grand Challenge applications collaborations.

Demonstrate prototype solutions of Grand Challenge problems that achieve and exploit teraops performance.

Provide and encourage innovation in the use of high performance computing systems and network access technologies for solving Grand Challenge and other applications by establishing collaborations to provide and improve emerging software and algorithms.

Create an infrastructure, including high performance computing research centers, networks, and collaborations that encourage the diffusion and use of high performance computing and communications technologies in U.S. research and industrial applications.

Work with industry to develop information infrastructure technology to support the National Information Infrastructure.

Leverage the HPCC investment by working with industry to implement National Challenge applications.

Enhance computational science as a widely recognized discipline for basic research by establishing nationally recognized and accepted educational programs in computational science at the pre-college, undergraduate, and postgraduate levels.

Increase the number of graduate and postdoctoral fellowships in computer science, computer engineering, computational science and engineering, and informatics, and initiate undergraduate computational sciences scholarships and fellowships.

Overview of the Five HPCC Components

Five integrated components represent the key areas of high performance computing and communications:

HPCS – High Performance Computing Systems

Extend U.S. technological leadership in high performance computing through the development of scalable computing systems, with associated software, capable of sustaining at least one trillion operations per second (teraops) performance. Scalable parallel and distributed computing systems will be able to support the full range of usage from workstations through the largest scale highest performance systems. Workstations will extend into portable wireless interfaces as technology advances.

NREN – National Research and Education Network

Extend U.S. technological leadership in computer communications by a program of research and development that advances the leading edge of networking technology and services. NREN will widen the research and education community's network connectivity to high performance computing and research centers and to electronic information resources and libraries. This will accelerate the development and deployment of networking technologies by the telecommunications industry. It includes nationwide prototypes for terrestrial, satellite, wireless, and wireline communications systems, including fiber optics, with common protocol support and applications interfaces.

ASTA – Advanced Software Technology and Algorithms

Demonstrate prototype solutions to Grand Challenge problems through the development of advanced algorithms and software and the use of HPCC resources. Grand Challenge problems are computationally intensive problems such as forecasting weather, predicting climate, improving environmental monitoring, building more energy-efficient cars and airplanes, designing better drugs, and conducting basic scientific research.

IITA – Information Infrastructure Technology and Applications

Demonstrate prototype solutions to National Challenge problems using HPCC enabling technologies. National Challenges are informationally intensive applications such as education and lifelong learning, digital libraries, health care, advanced manufacturing, electronic commerce, and environmental monitoring. IITA will support work to integrate technologies, such as services, software, and interfaces, to bring HPCC benefits to the general public. These will be leveraged across the National Challenges, leading to significant economies of scale in the development costs.

BRHR – Basic Research and Human Resources

Support research, training, and education in computer science, computer engineering, and computational science, and enhance the infrastructure through the addition of HPCC resources. Initiation of pilot projects for K-12 and lifelong learning will support expansion of the NII.

Evaluation Criteria for Agency Participation in the HPCC Program

Relevance/Contribution. *The research must significantly contribute to the overall goals and strategy of the Federal High Performance Computing and Communications (HPCC) Program, including computing, software, networking, information infrastructure, and basic research, to enable solution of the Grand Challenges and the National Challenges.*

Technical/Scientific Merit. *The proposed agency program must be technically/scientifically sound and of high quality, and must be the product of a documented technical/scientific planning and review process.*

Readiness. *A clear agency planning process must be evident, and the organization must have demonstrated capability to carry out the program.*

Timeliness. *The proposed work must be technically/scientifically timely for one or more of the HPCC Program components.*

Linkages. *The responsible organization must have established policies, programs, and activities promoting effective technical and scientific connections among government, industry, and academic sectors.*

Costs. *The identified resources must be adequate, represent an appropriate share of the total available HPCC resources (e.g., a balance among program components), promote prospects for joint funding, and address long-term resource implications.*

Agency Approval. *The proposed program or activity must have policy-level approval by the submitting agency.*

Agency Responsibilities

	ARPA	NSF	DOE	NASA	NIH	NIST	NSA	NOAA	EPA	ED
High Performance Computing Systems (HPCS)										
1 Research for Future Generations of Computing Systems	X	X		X		X	X			
2 System Design Tools	X	X		X						
3 Advanced Prototype Systems	X	X	X	X			X			
4 Evaluation of Early Systems	X	X	X	X	X		X			
National Research and Education Network (NREN)										
1 Interagency Internet	X	X	X	X	X		X	X	X	X
2 Gigabit Research and Development	X	X	X	X	X	X	X			
Advanced Software Technology and Algorithms (ASTA)										
1 Support for Grand Challenges	X	X	X	X	X	X		X	X	
2 Software Components and Tools	X	X	X	X		X	X		X	
3 Computational Techniques	X	X	X	X		X	X		X	
4 High Performance Computing Research Centers (HPCRCs)		X	X	X	X		X	X	X	
Information Infrastructure Technology and Applications (IITA)										
1 Information Infrastructure Services	X	X	X	X		X	X		X	
2 Systems Development and Support Environment	X	X			X	X				
3 Intelligent Interfaces	X	X		X		X	X			
4 National Challenges	X	X	X	X	X	X	X	X		
Basic Research and Human Resources (BRHR)										
1 Basic Research	X	X	X	X	X		X			
2 Research Participation and Training	X	X	X		X				X	
3 Infrastructure	X	X			X					
4 Education, Training, and Curriculum	X	X	X		X			X	X	

Agency Budgets by HPCC Program Components

FY 1994 Budget (Dollars in Millions)

Agency	HPCS	NREN	ASTA	IITA	BRHR	TOTAL
ARPA	103.9	48.7	32.3	95.6	18.4	**298.9**
NSF	19.8	47.9	119.3	19.0	61.0	**267.0**
DOE	10.8	16.6	73.8	0.3	20.7	**122.2**
NASA	11.5	13.2	73.1	12.0	3.2	**113.0**
NIH	3.4	3.0	26.1	13.6	11.7	**57.8**
NIST	0.3	1.9	0.6	15.3		**18.1**
NSA	21.5	7.1	11.2	0.2	0.2	**40.2**
NOAA		1.0	9.8			**10.8**
EPA		0.7	5.9		1.3	**7.9**
ED		2.0				**2.0**
TOTAL	**171.2**	**142.1**	**352.1**	**156.0**	**116.5**	**937.9**

FY 1995 Budget Request (Dollars in Millions)

Agency	HPCS	NREN	ASTA	IITA	BRHR	TOTAL
ARPA	110.7	61.1	29.6	140.8	15.2	**357.4**
NSF	21.7	52.9	141.2	50.6	62.2	**328.6**
DOE	10.9	16.8	75.5	1.2	21.0	**125.4**
NASA	9.7	12.7	81.2	17.5	3.8	**124.9**
NIH	4.9	8.4	23.8	29.1	15.6	**81.8**
NIST	6.8	3.7	4.6	41.4		**56.5**
NSA	16.1	11.8	11.8	0.2	0.2	**40.1**
NOAA		8.7	16.1	0.5		**25.3**
EPA		0.7	11.7	0.3	2.0	**14.7**
TOTAL	**180.8**	**176.8**	**395.5**	**281.6**	**120.0**	**1,154.7**

HPCCIT Reporting Structure and Subcommittee Roster

Office of Science and Technology Policy (OSTP)

Director: John H. Gibbons

National Science and Technology Council (NSTC)

NSTC Secretariat

Angela Phillips Diaz, Executive Director

Committee on Information and Communication (CIC)

Chairs: Anita K. Jones
Lionel S. Johns

Vice Chair: Melvyn Ciment

High Performance Computing, Communications, and Information Technology Subcommittee (HPCCIT)

Chair
Donald A. B. Lindberg

Executive Secretary
Charles R. Kalina

ARPA

Representative
John C. Toole

Alternates
Stephen L. Squires
Randy Katz

NSF

Representative
Melvyn Ciment

Alternates
Merrell Patrick
Robert G. Voigt

DOE

Representative
David Nelson

Alternates
John S. Cavallini
Norman H. Kreisman

NASA

Representative
Lee B. Holcomb

Alternates
Paul H. Smith
Paul E. Hunter

NIH

Representative
Daniel R. Masys

Alternates
Judith L. Vaitukaitis
Robert L. Martino

NSA

Representative
George R. Cotter

Alternate
Norman S. Glick

NOAA

Representative
Thomas N. Pyke, Jr.

Alternate
Ernest J. Daddio

NIST

Representative
James H. Burrows

Alternate
R. J. (Jerry) Linn

ED

Representative
Linda Roberts

Alternate
James A. Mitchell

EPA

Representative
Joan H. Novak

Alternate
Robin L. Dennis

OMB

Steven Isakowitz
Bruce McConnell

OSTP

Michael R. Nelson

Notes: The Advanced Research Projects Agency, the National Science Foundation, the Department and Energy, and the National Aeronautics and Space Administration hold permanent positions on the HPCCIT Executive Committee. Two other positions rotate among the other agencies; in FY 1994 these were NIST and NOAA.

Representatives of the Agency for Health Care Policy Research, the Centers for Disease Control and Prevention, the Indian Health Service, and the Food and Drug Administration of the Public Health Service of the Department of Human Health and Services; the Department of Agriculture; the Department of Veterans Affairs; and the National Communications System attend the HPCCIT Subcommittee meetings as observers.

Glossary

ACTS
Advanced Communications Technology Satellite, a NASA-sponsored program. A joint NASA/ARPA NREN collaboration will demonstrate high speed ATM/SONET transmission over the ACTS satellite, and will provide interface and operations experience in mating high speed terrestrial communications systems with high speed satellite communications systems.

Algorithm
A procedure designed to solve a problem. Scientific computing programs contain algorithms.

ARPA
Advanced Research Projects Agency, part of DOD

ASTA
Advanced Software Technology and Algorithms, a component of the HPCC Program

ATM
Asynchronous Transfer Mode, a new telecommunications technology, also known as cell switching, which is based on 53 byte cells

Backbone Network
A high capacity electronic trunk connecting lower capacity networks, e.g., NSFNET backbone

Bit
Acronym for binary digit

BRHR
Basic Research and Human Resources, a component of the HPCC Program

Byte
A group of adjacent binary digits operated upon as a unit (usually connotes a group of eight bits)

CERT
Computer Emergency Response Team

Computer Engineering
The creative application of engineering principles and methods to the design and development of hardware and software systems

Computer Science
The systematic study of computing systems and computation. The body of knowledge resulting from this discipline contains theories for understanding computing systems and methods; design methodology, algorithms, and tools; methods for the testing of concepts; methods of analysis and verification; and knowledge representation and implementation.

Computational Science and Engineering
The systematic application of computing systems and computational solution techniques to mathematical models formulated to describe and simulate phenomena of scientific and engineering interest

CIC
Committee on Information and Communication, part of NSTC

DOC
Department of Commerce

DOD
Department of Defense

DOE
Department of Energy

ED
Department of Education

EPA
Environmental Protection Agency

ESnet
Energy Sciences Network

FDDI
Fiber Distributed Data Interface

FIRST
Forum of Incidence Response and Security Teams

Flops
Acronym for floating point operations per second. The term "floating point" refers to that format of numbers that is most commonly used for scientific calculation. Flops is used as a measure of a computing system's speed of performing basic arithmetic operations such as adding, subtracting, multiplying, or dividing two numbers.

FNC
Federal Networking Council

Giga-
10^9 or billions of ... (e.g., gigabits, gigaflops, gigaops)

GOSIP
Government Open Systems Interconnection Profile

Grand Challenge
A fundamental problem in science and engineering, with broad economic and scientific impact, whose solution can be advanced by applying high performance computing techniques and resources

Heterogeneous system
A distributed system that contains more than one kind of computer

High performance computing
Covers the full range of advanced computing systems including workstations, networks of workstations with servers, scalable parallel systems, vector parallel systems, and more specialized systems. Scalable input/output interfaces, mass storage systems, and archival storage are components of these systems. Included also are system software and software development environments that enable users to view their workstations and the rest of their computing environments as a unified system.

HiPPI
High Performance Parallel Interface

HHS
Department of Health and Human Services

HPCC
High Performance Computing and Communications

HPCCIT
High Performance Computing, Communications, and Information Technology Subcommittee, part of the CIC

HPCS
High Performance Computing Systems, a component of the HPCC Program

IITA
Information Infrastructure Technology and Applications, a component of the HPCC Program

Interagency Internet
The federally funded part of the Internet that is directly used by the HPCC Program. It includes NSFNET, ESnet, and NSI.

Internet
The global collection of interconnect-

ed, multiprotocol computer networks including Federal, mid-level, private, and international networks. The Interagency Internet is a part of the Internet.

InterNIC
Internet Network Information Center

Interconnectivity
The ability of two or more computers to easily locate and communicate with each other over an infrastructure that provides the speed and clarity to accomplish a proposed task

Interoperability
The ability of any two computers that are interconnected to understand each other and perform mutually supportive tasks such as client/server computing

ISDN
Integrated Services Digital Network

Kb/s
Kilobits per second or thousands of bits per second

LAN
Local Area Network

Mb/s
Megabits per second or millions of bits per second

MIMD
Multiple Input Multiple Data

MPP
Massively parallel processor

NAPs
Network Access Points, a set of nodes connecting mid-level or regional networks and other service providers to NSFNET

NASA
National Aeronautics and Space Administration

National Challenge
A fundamental application that has broad and direct impact on the Nation's competitiveness and the well-being of its citizens, and that can benefit from the application of HPCC technology and resources

National Information Infrastructure (NII)
The integration of hardware, software, and skills that will make it easy and affordable to connect people with each other, with computers, and with a vast array of services and information resources.

NCO
National Coordination Office for High Performance Computing and Communications

Network
Computer communications technologies that link multiple computers to share information and resources across geographically dispersed locations

NIH
National Institutes of Health, part of HHS

NIST
National Institute of Standards and Technology, part of DOC

NLM
National Library of Medicine, part of NIH

NOAA
National Oceanic and Atmospheric Administration, part of DOC

NREN
National Research and Education Network. The NREN is the realization of an interconnected gigabit computer network system devoted to HPCC. NREN is also a component of the HPCC Program.

NSA
National Security Agency, part of DOD

NSF
National Science Foundation

NSFNET
NSF computer network

NSI
NASA Science Internet

NSTC
National Science and Technology Council

OMB
Office of Management and Budget

Ops
Acronym for operations per second. Ops is used as a rating of the speed of computer systems and components. In this report ops is generally taken to mean the usual integer or floating point operations depending on what functional units are included in a particular system configuration.

OSI
Open Systems Interconnection

OSTP
White House Office of Science and Technology Policy

Parallel processing
Simultaneous processing by more than one processing unit on a single application

Peta-
10^{15} of ... (e.g., petabits)

Port
Transport a computer program from one computer system to another

Portable
Portable computer programs can be run with little or no change on many kinds of computer systems.

Prototype
The original demonstration model of what is expected to be a series of systems. Prototypes are used to prove feasibility, but often are not as efficient or well-designed as later production models.

R&D
Research and development

Scalable
A system is scalable if it can be made to have more (or less) computational power by configuring it with a larger (or smaller) number of processors, amount of memory, interconnection bandwidth, input/output bandwidth, and amount of mass storage.

SIMD
Single Instruction Multiple Data

SONET
Synchronous Optical Network

Tera-
10^{12} or trillions of ... (e.g., terabits, teraflops)

T1
Network transmission of a DS1 formatted digital signal at a rate of 1.5 Mb/s

T3
Network transmission of a DS3 formatted digital signal at a rate of 45 Mb/s

vBNS
Very high speed Backbone Network Services

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